Canadian Centre for Mine Action Technologies

Le Centre canadien des technologies de déminage

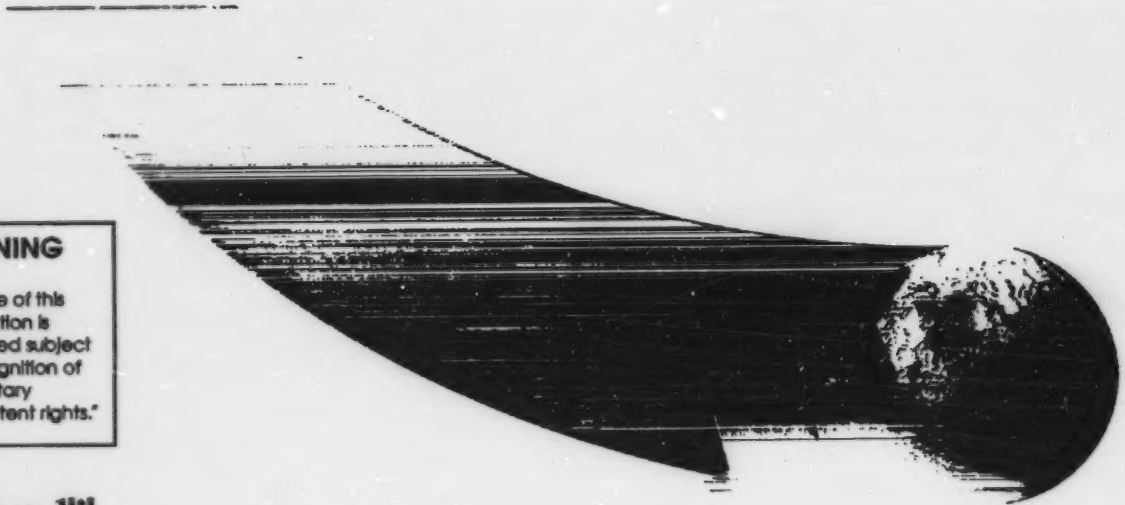
Scoping Study for Humanitarian Demining Technologies

Technical Report DRES-TR-1999-TR1

Al Carruthers, John McFee, Denis Bergeron, Yoga Das, Robert Chesney and Kevin Russell

Canadian Centre for Mine Action Technologies
Defence Research Establishment Suffield
Box 4000, Stn Main
Medicine Hat, Alberta T1A 8K6

September 1999



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DEFENCE RESEARCH ESTABLISHMENT SUFFIELD
BOX 4000, STN MAIN
MEDICINE HAT, ALBERTA T1A 8K6

TECHNICAL REPORT
DRES TR 1999-121

SCOPING STUDY FOR HUMANITARIAN DEMINING TECHNOLOGIES

by

Al Carruthers, John McFee, Denis Bergeron,
Yoga Das, Robert Chesney and Kevin Russell

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ABSTRACT

This report presents the results of a study carried out for the Canadian Centre for Mine Action Technologies (CCMAT). The aim of the study was to recommend a research and development program in humanitarian demining for the 5 year mandate of the Centre.

Current demining practices and problems, grouped according to survey level, are presented from a technical viewpoint. Demining needs are then presented in the same fashion. Next, brief reviews of the Canadian and worldwide demining research and development programs are presented to establish the current research and development status.

An assessment of technologies is then presented to determine future research and development directions for CCMAT. The general methodology used in a previous Defence Research and Development Branch countermine long term technology assessment was employed, but the guidelines were modified to reflect the differences between the requirements of humanitarian demining and those of countermine. Prescreening eliminated numerous technology areas and assessments were presented only for general technology areas which have some potential and/or novelty.

Based on the above assessment and requirements, a two component program in demining is proposed. The first component is an evaluation program for existing and future commercial off-the-shelf and prototype equipment. The second component is an in-house and contracted research and development program to develop technology specifically for humanitarian demining.

RÉSUMÉ

Ce rapport présente les résultats d'une étude effectuée pour le Centre canadien des technologies en déminage (CCTD). Le but de l'étude était de recommander, pour le mandat de cinq ans du Centre, un programme en recherches et développement (R et D) en détection humanitaire de mines.

On présente, d'un point de vue technique, les pratiques et les problèmes actuels; on regroupe ceux-ci selon le levé topographique approprié. On présente de la même façon les besoins en déminage. Ensuite, afin d'identifier l'état actuel de la R et D en déminage, on examine brièvement les programmes R et D canadiens et mondiaux en déminage.

On présente ensuite une évaluation des technologies afin de déterminer les directions futures en R et D du CCTD. Dans cette analyse, on a utilisé la même méthodologie que celle utilisée lors d'une étude à long terme des technologies anti-mines de la Direction de la recherche et développement pour la défense; on a cependant modifié certaines lignes directrices afin de tenir compte des différences entre le déminage humanitaire et le contre-minage. Un triage préliminaire a pu éliminer plusieurs technologies et on a analysé seulement douze domaines technologiques qui présentent certains potentiels ou nouveautés.

Suite à cette analyse et tenant compte des besoins, on propose un programme de détection de mines terrestres à deux volets. Le premier évaluera les détecteurs de mines commerciaux (ou les prototypes) existants et futurs. En second lieu, on propose un programme en R et D interne et par contrat ayant pour but le développement de détecteurs et de technologies connexes applicables aux besoins spécifiques du déminage humanitaire.

ACKNOWLEDGEMENTS

The efforts of a large number of persons were essential to the generation of this scoping study. Significant contributions were provided by the following individuals in the chapters indicated:

Chapter One and Two	Al Carruthers
Chapter Two, Three, and Nine	John McFee, Yoga Das
Chapter Four and Nine	Denis Bergeron, Robert Walker
Chapter Five and Nine	Denis Bergeron
Chapter Six	Al Carruthers
Chapter Seven and Nine	Robert Chesney, Doug Hanna
Chapter Eight	Yoga Das, Kevin Russell, Denis Bergeron, Al Carruthers
Chapter Ten	Al Carruthers

The valued input of numerous field experienced operators was most useful and essential to maintaining a practical view of real demining requirements. In particular, the advice and insight from Georges Focsaneanu, Harry Burke, Willie Lawrence, and David McCracken are gratefully acknowledged.

The talents and cooperative assistance of Betty Wedge are also acknowledged.

EXECUTIVE SUMMARY

The Canadian Centre for Mine Action Technologies (CCMAT) was established in August, 1998 as a joint venture between the Canadian Department of Defence (DND) and Industry Canada. The Centre was co-located with the Defence Research Establishment Suffield (DRES) to take advantage of expertise and facilities developed at DRES for the military countermine R&D program. One of the first tasks undertaken by scientific staff at the CCMAT was the preparation of a scoping study. This study reviews the state-of-the-art in humanitarian demining, military countermine and related technologies and forms a resource document for the Centre's program in R&D, test and evaluation and information exchange.

The scoping study consists of ten chapters, starting with an introduction that summarizes the mandate of the CCMAT. The five principle activities are information acquisition and dissemination, R&D, test and evaluation, modification to military countermine equipment and the investigation of alternatives to anti-personnel landmines. The introductory chapter also makes the point that the resources of the Centre are limited and the aim of the scoping study is to identify those technologies with the maximum potential for success and benefit to the demining community.

Chapter two defines humanitarian demining and recognizes that the problems in demining are very different from those encountered in military mine clearance. This chapter provides a useful summary of the many and varied sources of information on demining, which include experience within the military and defence R&D communities and the wealth of first-hand information on mine action published in books, periodicals and the electronic media. To supplement these sources, the Centre has begun a program of hosting technical seminars, by qualified individuals, and technical conferences. These activities form part of the Centre's role as an information clearing house.

Chapter three provides a summary of the huge worldwide effort being devoted to the problem of detecting low metal and nonmetal landmines. While most of this is R&D sponsored by the military and is directed to the countermine problem, it is presented here on the assumption that technological advances in military programs will have application to humanitarian demining. The writer does not describe in detail the wide variety of technologies being investigated for mine detection but refers the reader to excellent reviews, such as those written by DRES scientists, and conference proceedings (see the bibliography). The idea is to identify the centres of expertise in each country and to describe briefly the focus of their research. This review is intended to ensure that the CCMAT avoids duplicating R&D underway elsewhere and to provide a guide for future collaboration. Given the magnitude of the detection problem, collaboration between nations may be the only way to find a solution.

In Chapter four, neutralization of landmines is divided into three phases:

- preparation of the terrain to remove trip wires and vegetation
- prodding of the ground and excavation of the mine
- removal of the mine or in-situ demolition

The three phases are described in some detail with emphasis on the fact that the process is hazardous and highly labour intensive. The chapter proceeds to review mechanical assistance devices for removal of vegetation and breaking up the soil. Consideration is given to military countermine equipment (ploughs, rakes, rollers and flails) and to adapting civilian equipment designed for other applications. Commercial systems designed specifically for humanitarian demining (soil mills and sifters) are also reviewed with comments on their cost and maintenance requirements. The danger in exposing and extracting mines can be significantly reduced by new technology (air and water jets, quick setting foams etc.) provided these can be made more affordable and sustainable. Explosive and mechanical methods for destroying individual mines, in-situ, or collected mines, en-masse, are discussed. New technologies, such as binary explosives and water/abrasive cutting tools need to be evaluated and made more practical for humanitarian demining operations. Finally, the reviewer proposes that the wide range of technology options for mine neutralization be screened through rigorous field trials to identify those most appropriate for the demining community.

Chapter five covers protection for personnel and equipment in demining operations. It starts by reviewing the tasks performed by deminers, using information obtained from Mine Action Centres, such as those in Cambodia and Bosnia. The review then focuses on protection for the individual lying prone or crouching while using a prodder to locate a mine. It concludes there is an urgent need for affordable protective clothing that can be worn for long periods in hot climates without interfering with the sensitive task of mine location. To meet these design criteria, the developer will have to draw upon the data from a wide variety of sources. These include basic research on the physics of mine blast and on the mechanism of blast and fragmentation injury. Some of this essential information exists, developed during military weapons research, and can be adapted for demining application. The rest will come from basic research being conducted at centres like the CCMAT. This research will require innovative methods for investigating mine blast and simulating tissue injury, with sensitive instruments capable of recording transient phenomena. Some of the methodology already exists at the CCMAT and elsewhere and the reviewer urges collaboration between countries and standardization of test procedures. The approaches taken to developing improved protective clothing and equipment will take advantage of advances made in other fields, in particular materials science and anthropomorphic test devices. It is essential that this vast store of knowledge be collected in a format that enables dissemination to collaborators, especially industry. Finally, prototype clothing and equipment must be subjected to rigorous human factors analysis and field trials with demining personnel in realistic scenarios.

Chapter six considers what might be accomplished by the Centre in the area of victim assistance. The reviewer points out two major constraints, the lengthy approval process involved in the introduction of new medical equipment and the fact that the CCMAT is not staffed with medical personnel. In spite of these constraints, several useful avenues for investigation were identified. One of these is a survey of mine accidents, conducted with the help of outside medical personnel, to extract information for use in the development of better protective equipment. The review also suggests there is information available in other fields, such as military and civilian trauma medicine, that could be applied to improving medical kits and treatment in mine injury. The Centre would help in collecting and

disseminating this information and in making the medical community more aware of the specific needs of mine victims.

Enabling technologies are discussed in Chapter seven, specifically those that will support the detection and neutralization of landmines and the protection of deminers. One such technology is data fusion which has application to multi-sensor detection systems. Differential Global Positioning Systems (DGPS) and Geographic Information Systems (GIS) will be investigated for use in mapping areas where mines are located. Finally, automation and robotic technologies will be considered as a means of making mine clearance safer and more efficient. The intent of this part of the CCMAT program is to monitor developments in these areas and to investigate the most promising applications.

Facilities for test and evaluation are reviewed in Chapter eight. These include capabilities at the Centre for controlled laboratory testing and realistic field trials as well as access to practical testing at Mine Action Centres. The review makes the point that all candidate demining equipment must go through this sequence to have credibility with the user and emphasizes that all aspects, including human factors and survivability of the equipment in the field, must be evaluated. Chapter eight goes on to summarize the sophisticated facilities for test and evaluation available to the CCMAT through its association with DRES. These facilities, located on the Suffield Experimental Proving Ground (EPG), were developed by DRES to support R&D in mine detection and neutralization and personnel protection as part of its military countermine program. The Centre has begun expanding these facilities to better serve the needs of humanitarian demining. As elsewhere in this study, the reviewer recognizes the need for collaboration and indicates that Canada will participate actively in the International Test and Evaluation Program (ITEP) by contributing the sophisticated test facilities on the Suffield EPG and the expertise of the scientific staff at the CCMAT.

Chapter nine describes the assessment process for determining which technologies will be investigated under the CCMAT umbrella. Assessment criteria include time to demonstrate feasibility; human resources and financial cost; likelihood of success; R&D capability in-house and within Canadian industry; and relevance to humanitarian demining. A series of tables are presented rating each technology against the various criteria on a scale (very poor to very good).

The final chapter of the study contains program recommendations and conclusions. These are summarized in the table reproduced below.

TABLE 1: R&D OBJECTIVES OF THE CCMAT SCOPING STUDY

TECHNOLOGY FIELD (a)	HIGH PRIORITY (b)	LOWER PRIORITY (c)	DISCARDED (d)
1. DETECTION	- T&E of Smart Probe™ and follow-on development. - Point confirmation detector. - Characterize soil and effect on metal detector performance. - Discrimination capability for handheld detectors.	- Bioluminescence. - Long stand-off/ remote sensing of mined areas.	- Acoustic/ seismic detectors. - High power microwave. - Enhanced infrared.
2. NEUTRALIZATION	- T&E support to industry. - Modification/ minor development of small scale systems.	- Point neutralization of mines with explosives or small scale equipment.	- Large scale mechanical neutralization systems e.g., soil mills, flails. - Large area explosive neutralization devices.
3. PROTECTION	- Lower body protection. - Foot protection. - Head/eye protection. - Establish protection standards. - T&E support to industry.	- Upper body protection. - Hand protection. - Detailed injury mechanism studies.	- All round body protection. - Vehicle protection.
4. MEDICAL/VICTIM ASSISTANCE	- Assessment and minor upgrades to Trauma Kits. - Investigate practical, cost-effective solution to manufacture and fitting of artificial limbs.	- Feedback to medical staff.	- Development of new medical procedures or medical supplies.

5. ENABLING TECHS	- Produce simple generic tele-operation robotic kit for a wide variety of applications.	- Provide semi-autonomous capability to small scale equipment. - Automate highly repetitive tasks such as sweeping hand-held detectors.	- Geographical Information Systems. - Differential Global Positioning Systems. Highly complex systems such as fully autonomous systems.
6. TEST & EVALUATION (T&E)	- Establish and operate T&E facilities for detection, protection and neutralization technologies. - Provide in-theatre trial support as requested by demining agencies.	- Participate in the establishment of international T&E Program (ITEP). - Conduct ITEP trials.	- T&E of large scale neutralization vehicles. - T&E of large scale explosive neutralization devices.

SOMMAIRE

Le Centre canadien des technologies en déminage (CCTD) a été crée en août 1998, en association avec le ministère de la Défense nationale et Industrie Canada. Le Centre est situé sur les lieux du Centre de recherche pour la Défense de Suffield (CRDS) afin de bénéficier de l'expertise et des installations développées au CRDS pour le programme de R et D en contreminage militaire. Un des premiers travaux entrepris par le personnel scientifique du CCTD a été de préparer une étude préliminaire pour établir l'envergure des activités du CCTD. Cette étude examine les technologies de pointe en déminage humanitaire et en contreminage militaire ainsi que d'autres technologies qui s'y rattachent. Elle constitue pour le programme du Centre, un document de ressources sur la R et D, les essais et évaluations et l'échange d'informations.

Cette étude consiste en dix chapitres dont une introduction qui résume le mandat du CCTD. Les cinq activités principales sont l'acquisition et la dissémination de l'information, la R et D, les essais et les évaluations, la modification de l'équipement en contreminage militaire et les méthodes de rechange en matière de mines antipersonnel. Ce chapitre d'introduction insiste aussi sur le fait que le Centre a des ressources limitées et que l'étude a pour but d'identifier les technologies ayant le meilleur potentiel de profiter et d'assurer la réussite aux organisations de déminage.

Le deuxième chapitre donne une définition du déminage humanitaire et reconnait que les problèmes en déminage sont très différents de ceux de déblaiements de mines au niveau militaire. Ce chapitre fait une récapitulation très utile de nombreuses ressources variées en matière d'information en déminage. Elle inclue l'expérience en R et D des organisations du militaire et de la défense ainsi qu'une richesse d'informations de première main en matière de déminage. Ces informations sont publiées dans des livres, des périodiques et les médias électroniques. Pour augmenter ces ressources, le Centre a commencé un programme consistant à organiser des séminaires et des conférences techniques présentées par des personnes qualifiées. Ces activités font partie du rôle du Centre en tant que bureau central d'information.

Le troisième chapitre récapitule les énormes efforts faits au niveau mondial et qui sont voués aux problèmes de détection de mines faibles en métal ou de mines non métalliques. Bien que la plupart d'entre eux fassent partie de la R et D pour fins militaires et qu'ils soient dirigés vers le problème de contreminage, ces efforts sont quand même présentés ici sous la supposition que les progrès technologiques des programmes militaires seront applicables au déminage humanitaire. L'auteur ne décrit pas en détails la grande variété des technologies qui sont examinées pour la détection des mines mais réfère le lecteur à d'excellentes revues dont celles écrites par les scientifiques de CRDS et aux comptes rendus de conférences (voir la bibliographie). L'idée est d'identifier ces centres d'expertise dans chaque pays et de décrire brièvement les intérêts principaux de leur recherche. Cette étude a pour but d'assurer que le CCTD évite de répéter la R et D commencée ailleurs et de procurer un guide pour future collaboration. Étant donné l'étendue du problème de détection de mines, il se peut que la collaboration entre les pays soit la seule façon de trouver une solution.

Au quatrième chapitre, la neutralisation des mines est divisée en trois phases :

- la préparation du terrain pour enlever les fils de détente et la végétation
- le sondage du sol et le dégagement de la mine
- le déblaiement de la mine ou la démolition sur place.

Les trois phases sont décrites en détails en insistant sur le fait que la procédure est dangereuse et qu'elle demande un personnel nombreux. Le chapitre continue en examinant les appareils d'assistance mécanique pour enlever la végétation et pour travailler le sol. L'équipement en contreminage militaire tels que les charrues, les râteaux, les rouleaux et les fléaux sont considérés ainsi que l'adaptation de l'équipement civil créé, à l'origine, pour d'autres applications. Des systèmes commerciaux créés spécifiquement pour le déminage humanitaire (moulins de sol et tamis) sont aussi examinés et sont suivis de commentaires sur leurs coûts et leurs besoins d'entretien. Le danger de dégager et d'extraire les mines peut être réduit de façon signifiante par l'utilisation de technologies nouvelles (jets d'air et de vapeur, mousses à séchage rapide etc.) dans la mesure où elles sont rendues peu coûteuses et où elles sont durables. On y discute des méthodes explosives et mécaniques pour détruire sur place les mines individuelles ou encore pour leur destruction simultanée lorsqu'elles sont amassées. Certaines nouvelles technologies, telles que les explosifs binaires et les outils de découpage eau/abrasifs ont besoin d'être évaluées et d'être rendues plus pratiques pour les opérations en déminage humanitaire. Finalement, l'auteur propose que ce grand éventail d'options technologiques soit soumis à une procédure de sélection d'essais rigoureux sur le terrain afin d'identifier les technologies qui seraient les plus capables de répondre aux besoins des organisations de déminage.

Le cinquième chapitre traite de la protection du personnel et de l'équipement pendant les opérations de déminage. Il débute par l'examen du travail des démineurs et utilise l'information reçue par le Centre des technologies en déminage dont celle venue du Cambodge et de Bosnie. L'étude se concentre plus tard sur la protection des démineurs allongés ou accroupis quand ils utilisent une sonde pour localiser une mine. Elle conclut qu'il existe un besoin urgent de vêtements de protection peu coûteux qui pourraient être portés pendant de longues périodes dans les climats chauds et qui n'interféreraient pas avec le travail difficile de location des mines. Pour rencontrer ces critères de création, le développeur devra tirer ses données d'une grande variété de sources. Celles-ci incluent la recherche de base sur la physique du souffle des mines et sur les blessures causées par les explosions et les fragments. Quelques-unes de ces informations essentielles existent déjà. Elles ont été développées pendant la recherche sur les armes militaires et peuvent être adaptées et appliquées au déminage. Le reste viendra de la recherche de base conduite dans des centres tels que le CCTD. Cette recherche nécessitera des méthodes innovatrices pour étudier le souffle des mines et pour simuler les lésions des tissus humains, ceci à l'aide d'instruments sensibles capables d'enregistrer des phénomènes transitoires. Quelques-unes de ces méthodologies existent déjà au CCTD et ailleurs et l'auteur recommande vivement la collaboration entre les pays et la standardisation des procédures d'essais. Les approches prises pour développer et améliorer les vêtements de protection et l'équipement bénéficieront des avances faites dans d'autres domaines, en particulier les sciences des matériaux et les essais d'appareils anthropomorphes. Il est essentiel que ces données soient organisé sous une forme qui en facilite la dissémination à tous les collaborateurs dont plus particulièrement à l'industrie. Finalement les prototypes de vêtements et d'équipements doivent

Le neuvième chapitre décrit le processus d'évaluation qui déterminera quelles technologies seront examinées sous l'égide du CCTD. Les critères incluent la durée de temps pour démontrer la possibilité de réalisation, les ressources humaines, les coûts financiers, les chances de succès, les capacités de la R et D sur place et dans l'industrie canadienne et leur application au déminage humanitaire. Les tableaux qui suivent évaluent chaque technologie selon ces critères variés sur une échelle allant de très faible à très satisfaisant.

Le dernier chapitre contient les recommandations pour le programme et des conclusions récapitulées dans le tableau suivant.

Tableau 1 : Objectifs en R et D de l'étude d'envergure du CCTD

TECHNOLOGIES (a)	HAUTE PRIORITÉ (b)	FAIBLE PRIORITÉ (c)	REJETÉES (d)
1. DÉTECTION	- Essai et évaluation de la sonde instrumentée (Smart Probe™) et des développements futurs. - Détecteur de confirmation locale - Caractériser le sol et ses effets sur la performance des détecteurs de métaux. - Capacité de discrimination des détecteurs à main.	- Bioluminescence. - détection à distance (portées moyenne et longue) des surfaces minées.	- Détecteurs acoustiques et séismiques. - Micro-ondes à haute puissance. - Infrarouge amélioré
2. NEUTRALISATION	- Soutien à l'industrie en essais et évaluation. - Modification & développement mineur de systèmes de petite échelle.	- Neutralisation locale des mines avec des explosifs ou des équipements de petite échelle.	- Systèmes de neutralisation mécaniques de grande échelle. Ex : moulins de sol, fléaux. - Appareils de neutralisation par explosifs pour grandes surfaces.
3. PROTECTION	- Protection du bas du corps. - Protection des pieds. - Protection de la tête et des yeux. - Établir des standards de protection. - Soutien de l'industrie en essai et évaluation.	- Protection du haut du corps. - Protection des mains. - Études détaillées des mécanismes des blessures.	- Protection globale pour le corps - Protection des véhicules.

4. ASSISTANCE MÉDICALE/AUX VICTIMES	- Évaluation et amélioration mineure des trousses de traumatisme. - Examiner des solutions pratiques, efficaces et de moindres coûts pour manufacturer et installer des membres artificiels.	- Retour d'information au personnel médical.	- Développement de nouvelles procédures médicales et de fournitures médicales.
5. TECHNOLOGIES CONNEXES	- Production d'une trousse de téléopération robotique générique pour une grande variété d'applications.	- Procurer une capacité de robotisation semi-autonome pour équipements de petite échelle. - Automatiser les travaux très répétitifs tels que le balayage des détecteurs à main.	- Systèmes d'information géographique. - Systèmes de positionnement global différentiels. - Systèmes hautement complexes tels que des systèmes complètement autonomes.
6. ESSAIS ET ÉVALUATIONS (E&E)	- Établir et opérer des installations d'essais et d'évaluations pour les technologies de protection et de neutralisation. - Procurer sur place du soutien aux essais tel que requis par les agences de déminage.	- Participer à l'établissement international des programmes d'essais et d'évaluations. - Réaliser ces programmes internationaux.	- Essais et évaluations des véhicules de neutralisation sur une grande échelle. - Essais et évaluations d'appareil de neutralisation explosive de grande échelle.

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CANADIAN CENTRE FOR MINE ACTION TECHNOLOGIES

SCOPING STUDY

CHAPTER ONE

INTRODUCTION

BACKGROUND

The establishment of the Canadian Centre for Mine Action Technologies (CCMAT) was formally announced 24 August 1998. (Reference 1) CCMAT is a joint venture of two Canadian Government entities, the Department of National Defence (DND) and Industry Canada (IC). In very general terms, DND was to focus on research and development (R and D) and IC was to focus on commercialization and marketing. The CCMAT would be co-located with the Defence Research Establishment Suffield (DRES) in order to take advantage of the expertise and facilities developed at DRES in military mine clearance technologies.

A Project Charter was written for CCMAT and five principle activities were envisaged. (Reference 2) These were:

a. The information acquisition and dissemination activity will gather existing information about mines and humanitarian demining techniques and systems into a database and make it available to interested parties.

b. The test and evaluation activity will consist of developing standards for mine detection, mine clearance equipment appropriate for demining operations, and testing the equipment and related procedures to determine compliance with the standards. The activity will be conducted using the instrumented facilities, scientific procedures, and surrogate minefields at the Centre, and on-site in mine-affected countries using deployable instrumentation from the Centre.

c. Modifications to military countermine equipment. Military countermine equipment is aimed at fast, operational minefield breaching or landmine clearance of routes and tracks, primarily against anti-tank mines. Such equipment is not suited for humanitarian demining where safety rather than speed is the primary objective and the threat comes more from anti-personnel rather than anti-tank mines. R and D are required to adapt military landmine detectors and clearance equipment to the humanitarian role. Modifications to existing military mine clearance equipment will be developed in-house by the Centre staff and their wider application and exploitation brought about through contracts with Canadian industrial partners.

d. Investigations into Alternatives to Landmines. A number of governments have expressed unwillingness to ratify and implement the Convention (on the Prohibition, Use, Stockpiling, Production and Transfer of Anti-Personnel Landmines and their Destruction) because they view anti-personnel landmines as an essential

element in their defensive strategy. Studies by our allies indicate that, while there is no single technology or device that provides a one-for-one replacement for anti-personnel landmines, there may be alternative approaches that can accomplish the anti-personnel landmine function within the constraints of the Convention in some scenarios and for some threats. The Centre would study and document such alternative approaches and identify technologies necessary for their implementation. The results of these studies would then be made available to the governments of interested countries to encourage them to ratify and implement the convention.

e. Research and Development. The basic aim of the R and D program will be to develop new concepts in humanitarian demining, alternatives to landmines and to transfer the concepts to industry to develop new equipment and techniques for application worldwide. Specific activities will be identified in the scoping study but could include:

(1) Landmine detection, including multi-sensor handheld detectors, stand-off mine detection, differential global positioning mapping, and automated and robotic handheld detector technologies;

(2) Landmine neutralization using mechanical, explosive and directed energy means;

(3) Personnel and vehicle protection;

(4) Social and medical issues, including medical management activities stemming from research into landmine effects and diagnostics;

(5) Acquisition, modification and/or development of computer models to assess alternative to landmines; and,

(6) Development of sensor and command and control technologies as components of alternative systems.

The first problem facing CCMAT was to determine what specific technologies should be investigated and developed for the humanitarian demining application. It was clear that the demining requirements were different from the military countermine program, which was the focus of DND R and D efforts in the past. This prompted the requirement for a "scoping study" which would provide an outline plan. The technologies that would be pursued, the relative effort assigned to each, and what relative funding would be applied to each would be defined.

AIM OF THE SCOPING STUDY

The aim of the scoping study is to investigate and assess the spectrum of technologies that can be applied to demining operations.

OBJECTIVES OF THE SCOPING STUDY

The objectives of the scoping study are:

a. Obtain background information on demining requirements;

b. Compile a list of potential technologies;

c. Critically assess those technologies for application to the demining problem;

d. Identify and prioritize the technologies to be developed; and

e. Recommend short and long term objectives.

STUDY LIMITATIONS

Personnel at Defence Research Establishment Suffield (DRES) conducted the study, with valued input from numerous agencies and individuals of the demining community. Its focus is directed toward the formulation of an R and D plan. The commercialization and marketing aspect is the responsibility of IC and is therefore not reported as part of the study.

There are four main constraints, which limited the breadth and depth of the study. These should not be interpreted as severe limitations but rather factors which focused the efforts of the study team to those technologies and activities which are practical, within the mandate of CCMAT and are achievable within the resource constraints of the organization and Canadian industry. The four constraints are:

a. Budget. CCMAT was allocated $17 million. Up to $1.5 million has been committed for alternatives to landmine activities. (Reference 3) When personnel costs and funds for commercialization and marketing are deducted, this effectively leaves approximately $10.0 million to provide for R and D and services associated with the responsibilities assigned to CCMAT. What this effectively means is that costly, major projects are likely not affordable and careful planning is required to ensure that the funds are spent in the most effective manner possible.

b. Time. The anticipated lifespan of CCMAT is a total of four and a half years. Any projects undertaken must be capable of completion prior to the expiration of the CCMAT mandate in 2003.

c. Demining Community Requirements. The demining community has been exposed to a number of well-intentioned projects which originated without due consideration being given to the real requirements or conditions of the demining agencies in the field. CCMAT has made a concerted effort to carefully select projects that are cost-effective and practical for the demining community. Those projects which are too complex, difficult to sustain in a third world environment, or do not significantly benefit mine action activities must be discarded.

d. R and D Resources. There are a finite number of Canadian companies that can undertake the R and D in the technologies which are under consideration. The technological base of Canadian industry which has undertaken practical countermine/demining projects in the past is quite small.

It became apparent early in the scoping study that the study must limit the number and variety of technologies considered for development to those which have the most promise of success, be within the financial and time constraints of CCMAT, and would provide the most benefit to the demining community.

ORGANIZATION OF THE STUDY

The study begins with an introduction and background for the establishment of the Canadian Centre for Mine Action Technologies (CCMAT). The scope and limitations of the study are explained as well. Chapter Two defines the requirements for humanitarian demining equipment and highlights specific problems to be addressed during the study. Chapters Three to Six examine in some detail technologies which could be applied to detection, neutralization, protection, and medical/victim assistance fields. Chapter Seven, Enabling Technologies, studies technologies which could be applied to a number of fields. Chapter Eight describes the test and evaluation T&E requirements for Canadian and foreign equipment forwarded to CCMAT for assessment. Chapter Nine provides the assessment criterion that was used for the selection of the technologies which would form the basis for the CCMAT R&D program. Summary sheets are provided for the majority of technologies considered. Chapter Ten summarizes the conclusions of the study and outlines the technical program and relative levels of effort that will be followed throughout the CCMAT mandate. For convenience, a list of references used during the study is provided at the end of each chapter and a glossary of common demining terms is included at the end of the study.

REFERENCES

1. Government of Canada News Release, "Ministers announce creation of Centre for Mine Action Technologies", 25 August 1998.

2. Project Charter, "Research, Development, Commercialization and Marketing of Canadian Technologies in Support of the Government's Mine Action Initiative", August 1998.

3. Letter, Minister of National Defence to Minister of Foreign Affairs, dated 9 December 1998.

CHAPTER TWO

DEMINING PROBLEM DEFINITION

A key issue in formulating an R and D program is determining the real requirements of the demining community. The demining community has been burdened with a number of well meaning, but clearly impractical, technological initiatives which failed to take into account the requirements and environment of demining operations. Therefore CCMAT embarked on a study sub set which studied in detail the demining community requirements. CCMAT has sought the advice and expertise of Non-governmental Organizations (NGOs), subject matter experts, and groups such as Mine Action Canada which have considerable experience in the field and are knowledgeable of demining priorities and requirements.

INFORMATION SOURCES

Early in the problem definition phase of this scoping study, it was found that there was an abundance of information that would prove most useful. Much of this information is relatively new, and is the result of the efforts of the demining community to make their requirements known. Some of the information sources available to the CCMAT staff are outlined below.

Previous DRES Experience. Many of the personnel at DRES have extensive experience in the search for a solution to military mine clearance. The threat, i.e., the landmine, is the same in both cases. Therefore, there is considerable overlap between the search for a countermine solution and a demining solution. This expertise of the DRES scientific and technical staff has been augmented by attendance at demining technical conferences (Reference 1) and conducting test and evaluation of detectors in Cambodia and Bosnia for mine action centres. (References 2 and 3)

Technical Seminars. Mr. Georges Focsaneanu, was contracted to provide a concentrated four day session, 5 to 8 Oct 98, on the technological requirements of demining. References 4 and 5. In particular, he emphasised the importance of looking at the entire mine action process and not to just concentrate on the mine clearance task. His detailed knowledge of all aspects of demining and his personal experience in the organization and operation of mine action centres were most beneficial to those who attended that seminar and participated in the round table discussions and question and answer sessions. As opportunities occur, other persons were invited to brief on their experiences or provide additional information for the CCMAT staff. Two examples of this are a most informative briefing in September 98 by Mr. Willie Lawrence, UN Mine Action Centre (Bosnia) technical advisor, and the valued advice of Major Harry Burke who had just spent a year heading up the Test and Development Cell at Cambodian Mine Action Centre. Maj Burke provided a start point for technical requirements by summarizing areas requiring work and technical objectives for demining equipment. (Annex A)

Technical Conferences. More recently, the quality and technical content of demining conferences have seen considerable improvement. There is less rhetoric and more substantive issues are being discussed. Some conferences, working parties, and committees of experts are devoted primarily to demining technology. The proceedings of these conferences provide valuable insight into demining requirements. Examples of such conferences/meetings are the Copenhagen Conference 95, Sustainable Demining

(SusDem)- Zagreb 97, and Meeting to Discuss Humanitarian Mine Clearance Equipment Requirements - London 96. (References 6, 7, and 8).

Statements of Requirements (SOR)/Mission Need Documents (MND). These documents take a page from military procurement and are meant to accurately define requirements and specifications for a particular equipment. These documents are relatively new for demining equipment but are a valuable information source. Recent examples are those prepared by CMAC for mechanical clearance, brush cutting and mine detectors. (References 9, 10, and 11) The use of these documents and guidelines for mine action equipment procurement has become a much more formalized process and a clearer, more detailed equipment specification is the result. (Reference 12) This process provides equipment developers and manufacturers with a much more objective and accurate requirement baseline and provides details on specific country conditions and environment which have been neglected or ignored in the past.

Books, Periodicals, Electronic Media. There has been a virtual explosion of information regarding humanitarian demining across the spectrum of communications media. The multitude of web pages devoted to the subject numbers in the hundreds with more appearing every month. The list of references used for this scoping study gives an idea of the volume of open literature and other material that is available.

Specialist Studies. Many studies have been published on the search for a solution to the military countermine problem. References 13 and 14 are but two examples. Although the requirements for countermine operations and demining are different, there is sufficient overlap to warrant an examination of many previous studies on countermine. Some studies have been conducted specifically searching for a solution to the demining problem. One Canadian example of a private venture study was that conducted by the Prairie Agriculture Machinery Institute to investigate the use of agricultural, mining, and forestry machinery in a demining application. (Reference 15).

MINE DESCRIPTIONS AND THEIR DEPLOYMENT

In order to solve the demining problem, one must have accurate and detailed information about the actual landmines. Fortunately, there are many references available to describe the mines and how they operate. Reference 13 provides a general description on mines and how they function as well as how they are emplaced and deployed. These general descriptions and operating principles can also be applied to the mines found in humanitarian demining. Other useful open literature references include Janes Mine and Mine Clearance 97/98 and Brassey's Essential Guide to Anti-Personnel Landmines. (References 16 and 17) Other sources for technical information include references such as unclassified data bases (Reference 18) and unclassified military manuals (Reference 19). The landmine is often described as the main threat in demining operations. There is also a significant threat posed by unexploded ordnance (UXO) and other battlefield debris. Any equipment designed for demining must also take into account the likely presence of the UXO hazard.

DIFFERENCES BETWEEN MINE CLEARANCE AND DEMINING

Although the landmine is a common threat to both military countermine operations and humanitarian demining, there are significant differences which must be recognized before one makes the mistake of equating the two. There are marked differences between the requirements for mine clearance and

demining. Recognition of these differences and taking advantage of some of them will result in discarding some of the potential demining technologies and open the door for other technologies which could not be considered for military clearance operations.

Military minefields are usually characterized by recently laid modern or ultramodern mines. Most of the mines will be concentrated around installations or areas of military importance. Many of the minefields are marked by fences and detailed records may be kept. Military countermine operations seek to find the limits or boundaries of a minefield and then try to outflank or cross the minefield through narrow gaps or lanes. The latter operation is known as "breaching". The breaching can be done anytime during the day or night, in any weather, and often when exposed to hostile fire. Speed is of the essence and a typical target breaching speed is 15 km/hr. These stringent requirements mean that some mines would not be cleared (up to 20%) and that some casualties would be expected. The emphasis is on the clearance of anti-tank mines. Clearance methods often employ brute force e.g., explosive clearing charges, ploughs, etc., and can cause considerable damage to the area being cleared. Manual clearance methods are slow and extremely dangerous for the clearance parties. This clearance method is used as a last resort, particularly when a minefield is covered by an enemy's weapons.

Humanitarian demining operations focus on anti-personnel mines, however, anti-tank mines may be encountered, primarily on transportation arteries. Large numbers of UXO will be encountered. Most of the mines will be older generation, simple mines fitted with mechanical fuses. Many of the mines will have been in the ground for a prolonged period of time. Corrosion and other ageing processes may make the mine more unpredictable and more hazardous. Many of the mines will be laid at random, without any pattern, and will be located to create the maximum terror effect on the general populace and not just military targets. Most of the mines will be buried and/or well-camouflaged. Marking and detailed records of mine locations are rare or unreliable.

Humanitarian demining does have some advantages over military clearance operations. Normally, deminers are not being fired upon. Safety and reliable clearance of virtually all mines are paramount. The standard of clearance normally required by the United Nations is removal/destruction of mines to a "clearance standard of 100% with a tolerance level of not more than 0.4%" (Reference 12). Speed of clearance, although desirable, is not essential. Deminers can pick the time of day and wait for favourable weather conditions for clearance. There is some scope for preparing or conditioning the ground, if that will make the demining task easier or more effective.

Present humanitarian demining techniques are labour-intensive, hazardous, and will take decades to clear mine-affected nations. Technology, properly applied, and sustainable in developing countries offers the most promise for accelerating mine clearance in mine stricken regions. The clear definition of demining problems and the selection of suitable technology(ies) is an essential first step before embarking on a R&D program.

REFERENCES

1. Workshop on Sustainable Humanitarian Demining, Zagreb, Croatia, September 30 - October 2, 1997.

2. D. Rutkay, DRES Letter Report "Support to Cambodian Mine Action Centre Mine Detector Trial", 31 July 96.

3. UNMAC Report Summary - "Finding and Recommendations of the Report on Handheld Metal (Mine) Detector Trials Conducted in Bosnia during January 97." 10 Mar 97.

4. Georges Focsaneanu, Précis "DRES Technical Seminar, The Mine Action Process and the Requirements" dated 5 October 1998.

5. Georges Focsaneanu, Précis "A Functional Analysis of Mine Action", dated 1 October 1998.

6. The International Conference on Mine Clearance Technology co-sponsored by UN DHA and the Danish Government, Elsinore, Denmark - 2-4 July 1996.

7. Workshop on Sustainable Humanitarian Demining, Zagreb, Croatia, September 30 - October 2, 1997.

8. "Meeting to Discuss Humanitarian Mine Clearance Equipment Requirements" convened by Baric (Consultants) Limited (UK), London, UK 5-7 February 1996.

9. "Statement of Operational Requirement, Mechanical Mine Clearing for CMAC", Cambodian Mine Action Center, Draft dated 26 September 1997.

10. "Equipment Statement of Operational Requirement, #01099 Brush Cutters for CMAC", Cambodian Mine Action Center, Draft No. 1 of 26 January 1999.

11. "Draft Statement of Operational Requirement for Mine Detection", Cambodian Mine Action Center, dated 18 November 1997.

12. "International Guidelines for the Procurement of Mine Action Equipment - First Draft", UN Mine Action Service, October 1998.

13. J.E. McFee, Y. Das, A. Carruthers, S. Murray, P. Gallagher, and G. Briosi, "CRAD Countermine R&D Study - Final Report", Defence Research Establishment Suffield Report SSP 174, April 1994.

14. D. Rutkay, "Mine Neutralization Study - Task 031BF", Defence Research Establishment Suffield Report SR 632, July 1995.

15. "Database Search of Agricultural, Construction, and Forestry Machinery for Use in Humanitarian Demining", Prairie Agriculture Machinery Institute, Humboldt, Saskatchewan, Canada dated 16 March 1999.

16. "Janes Mines and Mine Clearance" edited by C. King, Second Edition, 1997-98, Janes Information Group Limited, Surrey, UK.

17. E. Banks, "Anti-Personnel Landmines - Recognizing and Disarming", Brassey's Inc, London, UK, 1997 (ISBN 1_85753_228_7).

18. CD-ROM "MINEFACTS©" Version 1.2, US Department of Defense, National Ground Intelligence Centre, Charlottesville, VA, 1997.

ANNEX A

OPERATOR NEEDS FOR HUMANITARIAN DEMINING

OPERATOR NEEDS	DETECTION	PROTECTION	NEUTRALISE	DISPOSAL	ENABLING TECHNOLOGIES	VICTIM SUPPORT
Provided by: - Mines Action Canada VVAF HI D Mil E CIDA	1. Close-In a. False Alarm Reduction b. Depth 20 cm c. PD+96% d. Faster Technique 2. Stand-Off a. Level 1 Survey Recce Tool b. 1km max. c. DGPS d. Selects Areas where Mech Equip can be used 3. Quality Assurance Tool a. Road Survey b. Confirm Level 3	1. Personnel: a. Foot/Legs: hold injury together b. Face and Eyes: shield from blast and frag c. Hands: shield from blast and frag d. Chest: shield from blast and frag	1. Mechanical: a. 2000 m^2/day b. Works hills c. Mines and ordnance up to 105mm d. Clears brush	1. Individual ordnance cheaper, deflagration vs detonation 2. Bulk field disposal 3. Bulk warehouse disposal	1. Next generation of GIS for demining operations 2. Select mechanical demining areas 3. Rapid intervention into a mined area. Mechanical site layout and prep 4. Better demining techniques. Retrain and re-equip deminers?	1. Site medic training 2. Village medical services/ equipment 3. Rehabilitation/ equipment
TECHNICAL ASSESSMENT DRES DREV DREO PAMI etc.	1. TI: Identify technologies that can meet the above areas in the next three years. 2. Existing Military: Identify tools the military use for the above tasks, assess how well they work. 3. Existing Civilian: Identify tools industry could adapt to the above tasks.					

INDUSTRIAL ASSESSMENT IC/TPC CIDA	Identify and pre-qualify Canadian companies that can provide engineering development of technologies shown above that can meet operator needs. This is an IC/TPC activity.

VVAF = Vietnam Veterans of America Foundation
HI = Handicap International
D Mil E = Director Military Engineers (DND-Canada)
CIDA = Canadian International Development Agency
PD = Probability of Detection
DGPS = Differential Global Positioning System
frag = fragments
105mm = 105mm Artillery Shell
GIS = Geographic Information System
TI = Technology Investment (DND program which examines "leading-edge" technologies)
DRES = Defence Research Establishment Suffield
DREV = Defence Research Establishment Valcartier
DREO = Defence Research Establishment Ottawa
PAMI = Prairie Agriculture Machinery Institute
IC/TPC = Industry Canada/Technology Partnerships Canada
CIDA = Canadian Defence Industry Association

CHAPTER THREE

DETECTION

PREVIOUS RECENT REVIEWS

In this report, we do not intend to describe in detail the wide variety of technologies that are available for mine detection and how each functions. This has been well addressed in previous available publications. The Threat Detection Group at the Defence Research Establishment Suffield (DRES) has been maintaining a watching brief of mine detection technologies for mines and unexploded ordnance (UXO) since 1975. They have written several reviews of mine detection technology [1,2,3,4] during that time, which have formed the basis for Canadian Department of National Defence (DND) research in this area for the last 20 years. The U.S. has conducted recent studies, such as the Jason Report [5] and an excellent review of mine detection research by the U.S. from 1960-1980 may be found in [6]. Australia has also done a fairly recent review of mine detection technology [7], which draws heavily from [1] and reaches essentially the same conclusions.

There are dozens of conferences each year on the subject of mine detection, although only a handful address the technology in a reliable manner. Of these, the most comprehensive and informative from a technological point of view are the SPIE Aerosense Conferences on Detection and Remediation Technologies for Mines and Mine-like Targets [8,9,10,11], which have been held annually since 1995. The IEE Conferences on the Detection of Abandoned Landmines [12], which started in 1996, are more oriented towards humanitarian de-mining and are also quite technically useful. Other conferences have concentrated more on political and operational issues [13,14].

In addition to the aforementioned formal publications, there are numerous Websites on the Internet dealing with mine detection. No attempt has been made to compile a list because of the general volatility of websites and because existing related sites can be easily searched. However, the websites of the Demining Technology Center (DeTeC) of École Polytechnique Fédérale de Lausanne (EPFI) and the U.S. Unexploded Ordnance Center of Excellence (UXOCOE) are worth examining.

CANADIAN PROGRAM

Mine detection research is carried out by the Defence Research and Development Branch (DRDB) of DND. DRES, an element of DRDB, is the lead agency. Mine and unexploded ordnance (UXO) detection research has been conducted since 1975, but has always been aimed at the military countermine scenario. The existing program focuses on a number of detection technologies which can be classified as airborne systems, land vehicle-mounted, and person-portable.

The present airborne detection research program focuses on the detection of scatterable or pattern minefields from airborne platforms. One component involves examining active and passive infrared imaging sensors, including a range-resolved active thermal infrared wavelength imager. A second component is the study of imaging of surface-laid and buried mines using visible/near infrared (VNIR) hyperspectral imaging systems. The third

component concerns investigation of the real-time analysis of images from both types of imagers to automatically confirm the existence of a minefield.

The vehicle-mounted program has centred around the Improved Landmine Detector Project (ILDP). The program which lasted from Fall 1994 to Fall 1998 led to the development of a teleoperated vehicle carrying a highly sensitive electromagnetic induction (EMI) detector, an infrared imager (IR), a ground penetrating radar (GPR), and a thermal neutron activation (TNA) detector for confirmation. Besides the system development, the project led to the development of state-of-the-art data fusion techniques, passive infrared performance prediction methods and a world leading TNA detector. Work in these areas continues. The ILDP system was trialled independently by the U.S. government in Summer 1998 and performed very well, being at least in the top 2 of 5 competing systems. It is also the only system with a confirming sensor, capable of reducing false alarms to operationally required levels. A follow-on contract is in place to produce 4 to 6 units for the Canadian Forces.

Person-portable detector research is focusing on multiple sensor detectors. It is felt that virtually all mines have sufficient metal to be detectable by a metal detector and so, research is concentrating on sensors that can be combined with metal detectors, such as GPR and X-ray backscatter detectors. Research done on UXO in the past concerning discrimination of metal pieces based on electromagnetic induction time signature analysis, will be reapplied to the low metal mine problem. A small project is investigating the use of a scanning arm with the capability of constant standoff from the ground. The arm would be mounted on a small, mobile, teleoperated platform and could sweep a "hand-held" metal detector or GPR in the same manner that a person does. This would remove the operator from danger and relieve the tedium of the search. The Smart Probe, now in preproduction, is a retrofit to the existing non-magnetic prodder which may allow rocks to be distinguished from potentially hazardous targets. In contact with a target, the prodder sends an interrogating, ultrasonic pulse down the needle. The return echo is analysed to identify the material contacted.

Some detection technologies under investigation can be applied to both vehicle-mounted and person-portable programs. These are confirmation technologies which must dwell over a suspect target, but have the capability of confirming the existence of a mine. Among these are electrical impedance tomography (EIT) and nuclear quadrupole resonance (NQR). They are initially being investigated as vehicle-mounted systems, but have the promise of being able to be reduced in size for person-portable use, either tethered to a vehicle or stand-alone. Another is trace explosive detection (TED), which was initiated in support of ILDP and has been ongoing at a low level since 1994, mainly through execution and analysis of detector trials.

As a complement to in-house research on metal detection, DRES routinely procures commercially available mine and UXO detectors to remain aware of the state-of-the-art. Over the years DRES has developed an expertise and testing methodology to evaluate detectors for their ability to meet various requirements. To this end, detector parameters such as detection sensitivity, electronic stability, susceptibility to moisture, mineralized soils and other environmental factors are critically assessed. This work is crucial in providing the Canadian Forces with unbiased advice on their equipment selection. This expertise has also been called upon by the Cambodian Mine Action Centre (CMAC) and the United Nations Mine Action Centre (UNMAC). At the request of CMAC in Spring 1996, DRES carried out a

comparative evaluation of available metallic-mine detectors in order to recommend detectors best suited to the Cambodian conditions, namely, a majority of hard-to-detect antipersonnel mines in a wet environment with an abundance of mineralized soil. DRES investigated and determined the cause of an apparent sensitivity to moisture of the Canadian in-service mine detector. In January 1997, DRES and UK MOD personnel completed a similar mission for UNMAC in the Former Republic of Yugoslavia.

FOREIGN PROGRAMS

It is important to know what Research and Development is being conducted in other allied countries in order that any proposed programs do not lead to a duplication of effort. An exhaustive description of all foreign programs would be a large document, well beyond the scope of this report. Instead, the following is intended to highlight the more significant foreign programs and give a flavour of what R&D is being done.

U.S.A.

By far the largest R&D program on military mine detection is being conducted by the United States. It has been ongoing since the 1950's, primarily by what is now the Night Vision Laboratory at Ft. Belvoir, VA, and to a lesser degree, by the Defence Advanced Research Projects Agency (DARPA). There are currently a large number of research and development programs. Some, such as the Multi University Research Initiative (MURI) and DARPA, are aimed at fundamental research, which may or may not have long term applications. Others are more applied, such as Hand-held Standoff Mine Detector System (HSTAMIDS), Ground-based Standoff Mine Detector System (GSTAMIDS), Airborne Standoff Mine Detector System (ASTAMIDS), Mine Hunter Killer and Cobra. Funding is provided by the U.S. Army and Marines through the Joint Mine Detection Program. Only a few of the more significant U.S. programs can be mentioned in the space allotted.

The Multi University Research Initiative (MURI) is one of the major U.S. research programs in humanitarian de-mining being managed by the United States Army Research Office (USARO). Funding for this program is at a level of approximately US$3M per year for 3 years plus optional funding for another 2 years. The research is being conducted by three main teams led by Duke University, Northeastern University and the University of Missouri-Rolla. Each of these teams, in turn, consists of a number of U.S. university and industrial partners. Research being conducted is primarily of basic long term nature and covers a wide variety of technologies.

DARPA has been funding fundamental research with potential, although often tenuous, applicability to mine detection since the 1960's. Indeed, some DARPA projects, such as elements of GSTAMIDS, have migrated into the U.S. Army's more applied programs. In the last two years, DARPA's efforts have been directed almost exclusively at trace explosive detection. DARPA, with major cofunding from the U.S. Marines, also funds development of an NQR detection system, with the ultimate goal of developing a hand held NQR mine detector which can be swept like a common metal detector.

HSTAMIDS is a program to develop multiple sensor person-portable mine detectors based on metal detection, GPR and passive thermal infrared imagers. The program has been ongoing for many years, with the first advanced technology demonstration in June 1995. Two U.S. companies continue to

compete. Performance exit criteria are a Pd of 90-100% for metallic and nonmetallic AT and AP mines, detection of AP mines to 7.62 cm depth, a FAR of 0.6 per square meter, scan rate of at least 10 square meters per minute, and a mine alert standoff requirement of 3-10 m. Total funding to date has been in the multimillion dollar range. Production was originally planned for FY01-FY04, but at the last ATD trials in Summer 1998, the detectors did not meet the exit requirements.

Mine Hunter/Killer advanced technology demonstrator (ATD) will attempt to demonstrate a system which can neutralize individual mines and other unexploded ordnance from a mounted platform at speeds of up to 32 km/h and standoff ranges up to 75 m, with a 98% probability of destruction. It will integrate advanced, but unspecified mine detection and mine neutralization technologies with automated targeting and fire control mechanisms. The project spans 4 years ending in FY00 and has a funding level for the neutralization component alone of US$33M. Probability of success is deemed to be very low by the authors.

The GSTAMIDS, also called Vehicular Mounted Mine Detector or VMMD, ATD program will attempt to demonstrate the capability to detect surface-laid and buried mines and other unexploded ordnance from a vehicle-mounted platform, through development of new sensors and integrating sensor fusion and automatic mine recognition techniques. It will provide feeder technology for the detection portion of the Mine Hunter Killer ATD. The Vehicular Mounted Mine Detector system must eventually achieve an 80-90% Pd with a FAR of 0.015-0.03 per meter of advance at a detection speed of 2-7.2 km/h. These goals (except for the speed) were almost achieved at trials in the United States during summer 1998. Four U.S. sponsored systems, three funded through CECOM, and one Canadian (DRES) system participated. The U.S. systems all employed EMI, IR and GPR sensors on an HMMV platform. The Canadian system was the ILDP system described above. However, the exit criteria, particularly the FAR, are insufficient for an operational system. (It should be noted that only the DRES system has a confirming detector with the capability to potentially reduce the FAR to operational levels.) Further, the systems are suitable only for roads and tracks and reliably detect only metal mines and anti-tank mines. They have little applicability to humanitarian de-mining. Funding for the ATD trial phase was US$9.2M for FY 97/98, but development of the U.S. systems prior to testing has been ongoing since the early 1990's at a cost of many millions of dollars.

ASTAMIDS is a project to develop an airborne minefield detection system that has been ongoing since the early 1980's with funding of many tens of millions of dollars. It consists of two competing airborne sensors, a passive thermal infrared line imager and an active short wave/passive long wave IR laser scanning imager. The ultimate goal is to detect minefield boundaries within 150 m with a Pd of 65% for buried pattern minefields, 70% for surface scattered, 80% for surface pattern and 60% for buried nuisance minefields. At the September 1997 ATD trial the systems performed poorly and at trials in Bosnia, it failed to detect any mines. It has since been returned to a program of fundamental investigation and will be competing with LAMIDS (see below).

Rapid Battlefield Mine Reconnaissance project will attempt to demonstrate, in an operational environment, capabilities for coastal area reconnaissance (beach, craft landing zone, and inland areas). The focus is on the airborne detection capabilities of the Coastal Battlefield Reconnaissance and Analysis (COBRA) technology demonstrator, which

incorporates multispectral VNIR video cameras in an unmanned air vehicle (UAV) for daylight countermine reconnaissance operations. A capability to detect minefields with a Pd of 0.8 and a probability of false alarm (Pfa) of 0.3 at an altitude of 150-300 m and at airspeeds of 110-185 km/hr is desired. Funding from FY 97 to 00 is US$12.3M, although the COBRA system has been funded for several years prior to 1997.

Lightweight Airborne Multispectral Countermine Detection System (LAMIDS) will attempt to demonstrate a standoff detection system integrated into the tactical UAV providing route reconnaissance, point detection, and minefield data to support operational planning and tactical manoeuvering on the battlefield. The project will focus on exploring new focal plane array (FPA) technologies, multi- or hyperspectral imaging, passive-solarization active sources, and electronic stabilization. The project started in FY98 and has a total funding of US$16.6M. The goal of the project is to develop a lightweight sensor payload for the tactical UAV while enhancing the performance over the current ASTAMIDS system sensors and detection algorithms. An ATD is planned for FY01.

Among the programs mentioned above, a wide variety of detection technologies and topics are being investigated. Following is a list of these topics.

a. Acoustics
   (1) Scattered Field
   (2) Resonance

b. Electromagnetic Induction
   (1) Electronic Target Discrimination
   (2) Auditory Target Discrimination

c. Radar
   (1) Ground Probing Radar(GPR)
   (2) Ultra Wide band SAR

d. Infrared
   (1) Assisted Infrared
   (2) Multispectral Imaging
   (3) Hyperspectroscopy and Polarisation Imaging
   (4) Airborne Active/Passive Infrared

e. Chemical Sensing
   (1) Polymer Sensor Arrays
   (2) MEMS-based Sensors
   (3) Bioreporter bacteria

f. X-ray Backscatter Imaging

g. Nuclear Quadrupole Resonance (NQR)

h. Other
   (1) Water Jets
   (2) Minefield Modification
   (3) Electrostatic Detection

The above U.S. programs, except for MURI, are all aimed at the military countermine problem. The U.S. also has an additional program specifically

aimed at humanitarian de-mining. It does not focus on high technology, as do the above programs, but rather it is aimed at producing simple, low technology aids to de-mining in a very short time frame. As such, there has been little output that was of any significance to detection.

EUROPEAN UNION

The countries with significant programs within the European Union are NATO members. Some of these programs are described in detail in [15] and will only be briefly summarized here.

Denmark has done a few experiments using 3000-5000 and 8000-12000 nm waveband IR cameras to simulate a vehicle mounted geometry.

France has a countermine detection program which includes both remote and close-in detection. In remote detection, work involves IR imagers based on new 8000-12000 nm waveband MCT array technology, with spatial resolution intended to detect AP mines at an altitude of 300 m. Multispectral VNIR imaging has also been done (600 to 900 nm waveband). Researchers are also working on algorithm development and implementation, including data fusion of IR and VNIR images. In close-in detection, R&D is ongoing on a 4 meter wide forward looking 500MHz-5GHz GPR. There is also a small effort on FLIR and visible imagers, mounted on vehicles, and some experiments have been conducted on thermal neutron activation.

Germany is part of a cooperative standoff minefield detection program with France and the UK. As of July 1996, they had received concept proposals from two consortia, with the definition phase for one concept planned for 2000. In close-in detection, there is a program to develop a multisensor vehicle mounted mine detector system, but this was in the planning stage as of July 1997. A small study is underway to improve metal detector performance by signal processing. Work in the past on a commercial GPR produced the standard results of poor signal to clutter ratio and so a small effort was started to design a better antenna to reduce ground reflections in a vehicle mounted geometry. The only somewhat novel concept under consideration is basic research into detection of buried mines by using a tank as a vibration source and employing a laser vibrometer to detect vibrational changes over the mine. Likelihood of success, based on previous acoustic/seismic research results, is small.

The TNO laboratory, The Netherlands, embarked on a multiyear, multimillion dollar humanitarian de-mining technology program in 1997. Short term (less than 3 years) goals are to develop an improved product for de-mining, ready for prototype testing in 3 years. In the long term, they wish to generally contribute to the world wide effort on the de-mining problem. They intend to procure and test commercial off-the-shelf (COTS) technology, develop detection systems and integrate them on platforms. They plan to investigate metal detection (single sensor and arrays), thermal infrared (TIR) imaging in 3000-5000 and 8000-12000 nm wavebands, ground probing radar or GPR (continuous wave and ultra wide band) and biosensors and chemical sensors. They recently established a very sophisticated detector test lane facility, worth approximately US$1 million, which will be very useful if cooperative international testing occurs. The Dutch have only been actively conducting mine detection research since the mid-1990's, chiefly on passive infrared and millimeter wave imaging.

The UK has a comprehensive standoff and close-in detection program. Because of a switch to agency status in the early 1990's, most of their research staff are relatively new. In standoff detection, they are concentrating on radar and have placed considerable emphasis on high resolution millimeter wave radar and ultra wide band radar. A lesser but more recently started program exists on narrow band synthetic aperture radar (SAR). Outside of radar, the UK has also investigated near infrared (NIR) to TIR wavelengths, emphasizing polarization to enhance detection of surface mines, and data fusion. Hand held detector research is also concentrating on GPR, with additional programs in NQR and a small effort in TIR imaging. Studies on data fusion and conductivity methods are planned. Since 1995, the UK has had a program to develop a vehicle mounted detector system. A sensor study was initiated in 1995 and some analysis of requirements and technical specifications has been done. The envisioned system is very similar to the ILDP, with the confirming sensor replaced by an NQR sensor.

Although there is a subcommittee of the NATO SGE on Combat Engineering dedicated to humanitarian de-mining, a number of the countries, such as the UK, France and Germany, do not have a mandate to conduct de-mining research unless it is directly applicable to the military problem.

Sweden has a small program devoted to mine detection. The Defence Research Establishment (FOA) in Linkoping is developing a hand-held impulse radar to detect non-metallic mines. The backpack portable radar has a 0.3-3 GHz bandwidth. Algorithms for detection and classification of buried objects have been developed at Chalmers University of Technology in close cooperation with FOA. Sweden has an interest in trace explosive technologies. The Swedish company Bofors Applied Technologies has developed a sensor based on an antibody-coated quartz crystal oscillator. It will lack the sensitivity for detection of vapour and likely will be too insensitive for explosive particulates in the soil surrounding the mine. The Swedish government, in 1997, purchased an EL/M-2190 vehicle mounted GPR system from Elta for evaluation. Numerous problems were encountered with the system, but the findings of the evaluation and the current status of vehicle mounted detection investigations are unknown. A private company, Humanity Dog, has been training mine dog teams since 1949. All their teams are trained and certified by the Swedish Dog Academy in Solleftea.

A consortium of institutes and companies from the Netherlands, Luxembourg, United Kingdom, Sweden, Portugal, Belgium and Germany, led by the International Institute of Aerospace Survey and Earth Sciences (ITC, the Netherlands), was recently formed to carry out an airborne remote sensing pilot project over four test areas in Angola. Funding of ECU 4.3 million (roughly CDN $7.6 million) was provided by the European Commission, the governments of Belgium, Germany, United Kingdom, Luxembourg, Portugal and the ITC. The objectives were to test various European sensors and multisensor fusion techniques for airborne minefield detection and to produce detailed maps showing the precise location of minefields in the Angolan test areas. Initial tests were conducted over simulated minefields in Belgium in July and September 1997. Various commercial colour and black and white visible and near infrared cameras were used, as well as X and P band radar. Slightly more than 75% of minefields and 65% of individual mines were detected. Based on the analysis of those data, reconnaissance and plans were made to carry out the final mine detection flights in November 1998. Because of deteriorating political conditions, the flights have been rescheduled from Angola to Mozambique. It is interesting to note that the radars detected

none of the mines and minefields in Belgium and are thus being dropped from the African trials.

AUSTRALIA

The Australian defence laboratory, DSTO, is concentrating on the detection of low metal content AP land mines. They are working with an Australian company who has developed a hand held metal detector which can suppress the signal due to mineralized soil. The same company is also in the process of developing a full width array, based on the same metal detector technology. DSTO has assessed the performance of the hand held detector, but most of the funding is internal to the company. DSTO is involved in development of a hand held GPR detector. The GPR is not yet fully developed. DSTO has other programs, including microwave assisted thermal infrared detection and vapour detection. DSTO also conducts limited testing of detectors in Australia. Australia at present has no mandate for humanitarian de-mining research.

SOUTH AFRICA

South Africa has considerable experience in developing detector systems for their own particular problem, essentially detection of large metal mines sporadically placed in a nuisance role. Thus, they have developed metal detectors capable of detecting large metal mines and have developed a successful system for wide area survey to detect roughly located mined regions. It is based on vehicle mounted vapour samplers which are checked off-line by explosives dogs at a base station.

CSIR Aerotek has a project to develop technology for the detection of minimum metal AP land mines. As of January 1998, the focus is on scenarios pertaining to the Southern African region, particularly countries like Angola and Mozambique. Current research is aimed at a multi-sensor suite consisting of GPR, IR and metal detectors. The sensors will all be COTS, but have not yet been selected. It is planned to image mines with the sensors and fuse the data. Preliminary studies on possible architectures are being performed in collaboration with the University of Cape Town Radar Remote Sensing Group.

SUMMARY

In summary, there is a large world wide effort, in both people, resources and funds, being directed at research and development on the detection of land mines. Most of the effort until quite recently has been directed at the countermine problem. A large number of countries are involved, although only a few are contributing, in a substantial manner, novel information or technology. Canada is recognized as being among the world leaders in mine detection technologies. A wide array of technologies are being investigated and substantial duplication of programs is present. No country or research group is close to solving the problem of detection of low metal and nonmetallic mines, particularly antipersonnel mines.

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CHAPTER FOUR

NEUTRALIZATION

INTRODUCTION

Depending on the theatre and mission, mine neutralization can include different activities. In Chapter 2, the differences between humanitarian demining and military clearance were outlined. The two missions differ greatly. In the military context, mine neutralization is often needed to preserve mobility. Speed is of the essence and the commander in the field expects to take mine casualties if it means not getting trapped in a zone covered by direct fire. Consequently, mine clearance operations are not geared towards doing a thorough job. On the other hand, the principle goal of mine neutralization in the humanitarian demining context is to remove all mines and UXO to return the land to civilian use. Finding and extracting all munitions is paramount. Hence, the military and humanitarian demining missions are conducted under very different constraints.

Countries with a post-conflict landmine problem have severe limitations in their logistical infrastructure. Roads and bridges are often in poor condition and need repair or rebuilding. Similarly, their industrial capabilities may be damaged, which severely limits their ability to manufacture and repair equipment, or to sustain high-technology initiatives. Finally, their economy is usually in ruins and they rely on foreign aid to restart proper economic activities. Hence, because of the combination of these factors with the need to remove all leftover munitions, manual clearance is the predominant neutralization method in humanitarian demining. It can be sustained with a minimum capital investment in equipment. Manual clearance requires substantial human resources. It is slow and often exposes personnel to serious injuries, but at the same time, it offers the highest confidence that a parcel of land is indeed clear of all mines and UXO.

Over the past decade, there have been many efforts to inject technology into the manual demining process. Some people call this "Mechanically Assisted Manual" demining, others call it "Accelerated Manual Clearance". For this study, we call will it "Mechanical Assistance". Originally, mechanical assistance evolved from an expectation that mechanical mine clearance equipment, that had been developed primarily for military purposes, could replace manual clearance in humanitarian demining. Most of the initial attempts showed that these machines could not reliably meet the thoroughness of manual clearance. At the same time, it also showed that the use of machines speeds up manual clearance by a factor anywhere from 2 to 10 because they condition the terrain and remove obstacles that otherwise slow down the manual demining process.

Humanitarian demining organisations were initially slow to accept mechanical assistance. They would not see beyond the relatively large capital investment that it requires. However, if the machines allow the overall demining process to be performed faster, it can shown that it offers definite cost advantages when one considers the overall cost per square metre and time required to do the job. Demining organisations are slowly accepting this fact. Industry and universities, often funded from government programs or from charitable donations, try to capitalise on this and are proposing a broad range of equipment solutions. The latter range from simple individual tools to enhance productivity to large mechanical systems that can process

mine detectors* is greatly reduced if the distance between the detector head and the ground is not kept at a minimum. It is therefore necessary to remove the vegetation down to ground level.

A variety of vegetation may be encountered. Many places have some form of grass growth that is rarely less than one meter high. Flowers, ferns or small brushes, are often found. Some of the vegetation has thorns, small or big, that can present a serious impediment to deminers. Bamboo, softwood and hardwood trees may be present. Not all vegetation gets removed. Trees with a trunk diameter greater than 10 cm may be left in place if it is determined that the tree was in place before the conflict or that a UXO or mine cannot be present below it.

Removal is done using a variety of hand tools, such as secateurs, handsaws and shears. A deliberate effort is made not to use any vertical motion that could result in accidental contact with the ground. Removal of the vegetation is accomplished starting at the top, cutting short sections that are deposited in a safe area. Every effort is also made not to disturb the vegetation outside the local area as it could trigger a trip wire or fall atop a buried mine. It can be seen that the terrain preparation phase can be time consuming in tropical regions where the flora is aggressive. For example, the Cambodian Mine Action Centre (CMAC) estimated that their deminers spend up to 65%-70% of their time removing vegetation. If technology can be used to reduce this time in half, there would be substantial gains in the efficiency of the process.

PRODDING AND EXCAVATION PHASE

Once the vegetation has been removed, a deminer sweeps the area to detect the presence of metal. If nothing is detected, the deminer moves forward by a ½ meter and starts the terrain preparation procedure all over. On the other hand, if the metal detector produces a signal, the area is marked and manual prodding is used to investigate the presence of mine-like objects. There exist several types of prodders, from a simple mild steel rod with wooden handle to sophisticated probes made of non-ferrous or non-magnetic materials with ergonomically shaped handles.

Soil compaction and the presence of roots have a strong effect on the prodding process. It is important to apply as little force as possible to the prodder. Procedures have been developed to start prodding ahead of the point of detection so that the soil may be excavated. This allows prodding from a perspective that increases the probability that the probe tip would contact the side or underside of a mine, thereby minimising the chances of initiating its detonation. For hard soil conditions, water may be used to loosen it.

If a mine-like object is found, an excavation procedure is initiated to uncover the object for further inspection. Some demining organisations adopt the policy that the mine is uncovered only sufficiently to identify it positively and to allow a contact patch large enough for a demolition charge. Other organisations allow the complete uncovering and removal of the mine,

* At the time of writing, most mine detectors operate on the principle of metal detection. It is well known that the performance of these detectors degrades rapidly as the mass of metal decreases and as the distance between the detector head and the metal object increases. The metal content of many mines is therefore minimised for these reasons.

which is then neutralized according to standard EOD operating procedures and destroyed in a pit at the end of the work period.

The prodding and excavation phase takes several minutes to complete. Based on statistics from CMAC, less than 1% of the objects exposed are mines. Therefore, there is scope to save time if appropriate technology is introduced during this phase. Furthermore, this phase is the time when deminers are exposed to a substantial risk of injury. Technology may offer a way to move people some distance away where their probability for injury is greatly reduced.

REMOVAL OR DEMOLITION PHASE

If a UXO or mine is found, appropriate procedures are used either to disarm it for removal to a destruction site, or to destroy it in-situ. In either case, humanitarian demining organisations rely on donated explosives for the demolition portion of this work. The explosives may be old and not necessarily reliable. Given that these explosives are obtained through donations, they are cheap, but the cost advantage can easily be lost if a batch of explosives is unreliable and expose personnel to unnecessary risks.

Another factor to consider is that import rules for explosives vary from one country to the next. This often puts an extra bureaucratic strain on some organisations. It may be possible to develop binary explosives for which individual components are not classified as explosives. Each component can then be imported under less stringent import laws. The same advantages apply to the transport requirements and costs.

TECHNOLOGY FROM MILITARY COUNTERMINE

Military countermine equipment is usually designed to fulfil three missions: breaching, area clearance and route proofing. Breaching is done under combat conditions to cross a minefield. The focus is on anti-tank mines and the breaching vehicles must be able to follow other armoured vehicles and carry sufficient armour to protect itself against blast and ballistic threats. These requirements invariably lead to very heavy vehicles that are poorly suited to humanitarian demining. The working end of these systems is either based on mechanical principles such as rollers, ploughs, rakes or flails. Explosive breaching techniques are also used where several tons of explosives are deployed and detonated. This approach is clearly not a valid option in the context of humanitarian demining. It will not be discussed further in this study.

Area clearance is needed to ensure that bivouac and logistic support areas are clear of anti-tank and anti-personnel mines. The requirements of this mission are essentially the same as for humanitarian demining, and it is usually done in the same manner, i.e., using manual clearance techniques. In fact, most of the manual clearance techniques in humanitarian demining were adopted from the military. Finally, route proofing is a specialised function that is normally done with rollers to ensure that the road is clear of anti-tank mines. It does not require to clear vegetation or to loosen soil.

Because of the requirement to operate under combat conditions, most of the military countermine equipment is usually very massive, and consequently, difficult to move around. Furthermore, it often entails a complex logistics tail that is beyond the resource capabilities of humanitarian demining

organisations. However, as will be seen, some of the working principles from military mechanical breaching equipment can be - and have been - adapted successfully to humanitarian demining.

MECHANICAL ASSISTANCE TO MINE CLEARANCE

From the above description of manual clearance, it is clear that mechanical assistance can provide substantial benefits in terms of speeding up parts of the process and in potential reductions of the risk of injury to personnel. Many technical solutions have been proposed for specific phases of the process. By and large, they stem from adaptations of equipment used in civilian life for agriculture and other sectors of the economy that need to perform tasks similar to those in humanitarian demining. Examples are readily found in industries such as forestry, mining, construction, highway maintenance, bush clearance under high-tension power lines, etc.

Many factors will affect the selection of appropriate technologies for mechanical assistance. First, the *mission* at hand may be to clear living areas, agricultural areas and water access pathways in order to resettle a group of displaced persons. Alternatively, it could be to rebuild the transportation and other public infrastructures in order to re-establish some level of economic activity within a country. A second factor is that the equipment type and how rugged it is must be matched to the *threat* distribution. The latter might include various UXO and landmines, with attention given to the ratio of anti-tank to anti-personnel mines. A third factor is the *environment*. The type, size and density of vegetation, and the extent of the root structure, dictate what tools can or cannot be effective. Topography, soil characteristics and the presence of natural or man-made obstacles, e.g., termite hills and trenches, also affect the choice of equipment. Finally, giving appropriate considerations to the *logistics* and *infrastructure* required to transport, operate and maintain the equipment is paramount.

As an aside, it should be mentioned that there is some debate as to whether or not removal of trip wire via mechanical assistance contaminates the terrain further by spewing metal fragments in the area that is being cleared. In certain climates, trip wires are known to degrade with time while the mechanism of many fuses freezes up. Hence, after a while, fragmentation mines are rendered useless. Therefore, it appears to be a need to analyse the trade-offs of time benefits that result from mechanical removal of trip wires, combined with vegetation removal, as compared to the additional time spent with detectors. It is also reported that deminers feel safer working on a parcel of land that has been prepared with mechanical assistance equipment. The power of this psychological factor should not be neglected, as long as it does not result in complacency.

VEGETATION REMOVAL

The first order of business in manual clearance is to remove trip wires and vegetation. In some theatres, the flora is quite aggressive. Individual tools and mechanical assistance solutions proposed for this role may be classified according to whether or not an attempt is made to minimise disturbances of the ground surface. The basic premise of minimising ground disturbance is to allow an effective visual inspection of the ground before using the mine detector. A variety of mulching and stump grinding equipments have been proposed or are in their testing phase. In general, these

implements are mounted on a hydraulic boom mounted on an excavator, a backhoe or, in some cases, on armoured military chassis. In all cases, an attempt is made to protect the operator from accidental explosions with more or less extensive armouring of the control cabin.

A grapnel system was developed to address the problem of trip wires. This system consists of a grapnel launcher and winch that are mounted on a trailer. Operationally, the trailer is brought near the edge of the lane to clear and is launched fifty metres ahead. It is then dragged back with the intent to activate any trip wires in its path. This approach may be useful in many situations, but it is also prone to entanglement and getting stuck in many cases. Another tool proposed is an extended length weed eater or mower. The operator is several metres away behind a transparent shield. The intent of this equipment is to increase the standoff between the operator and any potential mine. It has its limitations. The length of the device makes it awkward to operate. From a protection point of view, the shield may be effective is the device activates a blast mine, but may not be effective at stopping the fragmentation from the larger fragmentation mines.

Reports from the field indicate that mulching and stump grinding do improve the rate of demining. However, some considerations must be made to clear the area of mulch and other residues generated in the process. Possible technologies include simple sweeping, air jets, manipulators with scrapers, etc.

Techniques from the forestry industry can also be used to harvest trees and shrubs that have a stem or trunk sufficiently large that it requires sawing or shearing. These systems sometimes use the combination of a gripper with a horizontal shear or a chain saw. The use of water jet cutting has also been proposed. Pearson Industries have modified a commercial tractor with a gripper and shears system. The equipment may be useful in some theatres. For areas with light overgrowth, mowers and hay harvesting equipment can be useful. Again, provisions need to be made to protect the operator from an accidental explosion.

Several technologies remove the vegetation, but also break the ground surface at the same time. The flail is probably the most widely spread method proposed in that respect. The working principle is to repeatedly strike the vegetation and beat the ground with rotating masses attached at the end of cables or chains. A variety of strikers have been designed to optimise the cutting, shearing or pounding action. On some systems, several striker types are mixed on the same flail drum. Depending on the size and power of a system, and the nature of the ground, mines can be attacked down to depths as great as 20 to 50 cm. The speed of advance can vary widely, but rarely exceeds 1500 meters per hour.

There exists many flail systems. The larger systems, such as the Aardvark, the SISU and the Keiler, as adaptations from military countermine that clear a 3 to 4 metre wide swath. Some medium size systems, up to three metres in width, have been mounted at the end of an extension boom or of an excavator arm. The latter implementation presents the advantage that they can clear in ditches and other high slope areas. Systems where the flail is mounted more or less rigidly to the prime movers can only be used in less challenging slope conditions. An on-board operator usually operates the large and medium size systems mentioned above; hence proper armour protection of the cab is required.

Although large flail systems are self-propelled, their size and weight often makes it difficult to navigate on narrow roads and weakened bridges. In response to this, several mini-flail systems have been developed over the past few years. These systems clear a 1 to 1½ metre swath. They are less powerful and, consequently, less effective than their larger counterparts, operating only near the surface unless the speed of advance is brought to zero and the head is used to locally dig. For example, the Slovak Bozeña mini-flail, which is equipped with a head that moves up and down by ±15 degrees, can dig down to a depth of ½ metre in this fashion. Due to their small size, mini-flails are operated remotely, which sometimes adds to the complexity of the system. At the same time, their smaller size presents advantages in regard to maintenance. There is also an attempt to design a mini-flail so that it can be sustained from in-country resources as much as possible. The Tempest flail is the embodiment of this effort.

In general, flail systems clear the overgrowth, soften the soil and provide some assurance that trip wires are effectively removed. The depth of operation is usually adequate. Some limitations of flails have also been uncovered. There are reports that mines have been flung aside, instead of being destroyed, which could result in a more dangerous situation as the mine could be left in an unstable state. Some striker designs and the entanglement of adjacent chains leave skip zones, i.e., areas of ground left untouched. For some terrain conditions, the flail does not strike the ground completely and the blast shield acts like a bulldozer blade to bury mines in depressions to even greater depths. Finally, when operating in dry soil conditions, the flailing action generates a large dust cloud that obscures the vision of the operator and often leads to path divergence.

Another technology that clears vegetation while processing the ground to a substantial depth is soil milling. Soil mills typically use a series of cutting implements mounted on a heavy rotating drum in front of a prime mover vehicle. The premise is that the rapid cutting action of the system destroys any mine before it detonates. Existing systems by Bofors and Krohn are large and armoured to withstand an AT mine blast. They operate to depths of 30 - 50 cm, processing everything in their path. The major consideration with these systems is their size and large mass, of the order of 40 - 45 tonnes, which requires a good road and bridge system to be in place for in-country transport. Furthermore, they are complex and expensive to maintain.

An alternative implementation of the soil mill is to mount a working end on an excavator arm. This is the case of the Uni-disc system. This presents similar advantages to those for flails, i.e., that the tool can reach in places that would otherwise be difficult for the vehicle mounted system.

GROUND PROCESSING AFTER VEGETATION REMOVAL

Once vegetation has been removed, the choice of operations to carry out depends on the condition of the soil surface. For cases where minimal soil break-up has occurred, the regular procedure is to sweep the area with a mine detector. Alternatively, it may be desirable to precede this step with a proofing stage to activate as many buried blast mines as possible. The mine roller principle can be useful for this purpose.

Military mine rollers could be used at this stage, however, most of these devices were designed to withstand up to five detonations of an anti-

tank mine with 10 kg of explosives. As a result, they are very heavy and must be pushed in front of a heavy vehicle such as a tractor or Main Battle Tank. One such implementation is the Panther system, a remote controlled M60 tank with track-width mine roller. Rollers can reach an operating speed up to 30 kph depending on soil type and terrain. However, they are likely to get stuck in soft soil, and have difficulty to clear a mine buried in a small ditch or along terrain ridges. Track-width roller systems require multiple passes to completely clear an area. It should be noted that some full-width rollers were designed but generally found to be impractical because of their excessive mass.

An interesting mine roller system was implemented by a company in South Africa. It consists of a Caspir-class mine-resistant vehicle equipped with steel wheel. This manned vehicle was used to clear AP mine fields by driving the vehicle back and forth across the field, thereby causing a large number of mines to detonate. The strength of the wheel had been selected to resist an AP mine detonation with minimal damage, but an AT mine would have caused a mobility kill, albeit with a low probability of injury to the crew of the vehicle. Other mine roller configurations have been proposed. For example, the US Humanitarian Demining program tested a multi-component neutralization system where the prime mover tows a mine roller array. Another suggestion is to use agricultural pack wheels as mine rollers. The latter are relatively inexpensive and easy to repair in the field.

The Whirling Dervish presents an innovative mine roller implementation. The goal was to design a roller that applies sufficient force to detonate AP mines, but not heavy enough to initiate AT mines. The resulting device is a relatively lightweight (less than 350 kg) open frame structure with three wheels disposed on the outside at 120 degrees from each other, thereby forming an equilateral triangle. The wheel axes point to the centre of the triangle. If all wheels are driven at the same speed, the device simply turns about its centre. However, small cyclical variations of wheel speed allow the device to follow a path on the ground. It is then claimed that every point on the ground can be rolled over twice during the advance of the device. The dervish appears to present other advantages. The open frame gives the design good mine strike survivability. Furthermore, the wheel materials were tested and shown to survive an explosion with 500 grams of high explosive.

Pre-processing with rollers should reduce the risk to deminers that follow with a mine detector. If the detector generates a signal, the procedure is to identify the source of this signal. If the soil is soft, this can be done readily, but this is often not the case. In some theatres, the root structure is extensive and can combine with hardened clay to pose a significant obstacle to the operation of mechanical systems. Even without a significant root structure, a compacted soil makes it extremely difficult to prod. Therefore, it is often desirable to break-up and loosen the soil before prodding takes place. Irrespective of how this operation is done, it should meet the UN requirement that calls for topsoil clearance down to 20 cm, the typical depth of a farm plough.

Different approaches to soil break-up have been proposed. Some people advocate the processing of large areas; others propose tools to speed up the processing of a small area where the mine detector generated a signal.

Within the realm of area clearance techniques, ploughing may be adopted from military countermine. Ploughs usually consist of a mouldboard with a

series of teeth that penetrate the ground to lift mines. The teeth's spacing is selected for anti-tank mines but could be reduced to handle anti-personnel mines. The soil and the mines are displaced to the sides of the furrow for later removal or destruction. In some cases, mine detonation can occur, but the equipment is usually designed to survive an AT mine blast. Typical plough speeds vary from 3 to 10 kph, depending on the soil and terrain conditions. Some limitations of ploughs include depth control, soil sensitivity with a tendency to get bogged down in soft soil and difficulty to cross some ditches.

Ploughs are stated as being 90% effective at clearing anti-tank mines down to a depth of 10 cm, although some manufacturers claim a 30-cm depth. To achieve this depth, sufficient traction must be available. In compacted soil, a full width plough (about 4 metre) requires a large bulldozer as prime mover. It is feasible to reduce the size of the machinery if one accepts a narrower furrow. Alternatively, less traction is required if the depth is reduced. This was implemented in Angola where a grader was used to plough mined roads. In that particular case, ploughing was preceded by manual clearance. The grader would then remove a layer of soil, and the manual clearance would be repeated.

The rake is a variation from the plough, designed to remove mines from sandy soil. Its open frame design allows the soil to flow through the mouldboard while the mesh spacing determines the mine size that can be extracted. The goal is to deposit any object larger than the mesh size to the sides of the cleared lane. Due to their flow-through nature, rakes require less tractive power than ploughs. They are effective in loose, sandy soil situations, but are not considered suitable for most other soil conditions.

Other techniques to break up the soil and root structure over large areas may be adopted from the agricultural industry. The US modified a cultivator to be pushed or side-pulled for this purpose. This device can even extract some mines, but in general, it is necessary to follow the cultivation step with some form of soil processing. Various sift and soil-sieving devices have been proposed for this role. For example, a company in the UK proposed a modified potato picker called the Uni-Sift. This system drives a modified plough-screen 30 cm into the ground. The soil and content picked up is conveyed up to a large sifting bed where the soil falls back to the ground and all rocks, mines, etc. are discharged to one side and laid in windrows for follow on clearance. This system works well in farmers' fields but fails in harsher terrain with a strong root structure or large buried obstacles. Other systems similar to the Uni-Sift include rock pickers and beach cleaning equipment, such as that proposed by the US for berm processing in South Africa. These devices are useful for specific applications, but are also sensitive to soil type and can clog if soil cohesiveness is high.

LOCALIZED SOIL PROCESSING TECHNOLOGIES

Several tools and techniques have been proposed to process the soil in a small area surrounding the location of a detection signal. The intent is to speed up the process, make use of the force magnification offered by hydraulic power in cases where the ground is very hard, or simply to increase the standoff from the mine. In Afghanistan, some organisations use a regular backhoe to scrape the soil surface in areas where the ground is very hard. The cab of the machine is equipped with light armour. This level of protection is adequate for small blast mines, but would likely not be

sufficient for fragmenting munitions or larger mines. The survivability of the equipment may be improved if the bucket is replaced by an open structure that allows more venting of the detonation products. This was done in South Africa where a manipulator arm was mounted on a mine-resistant vehicle. It was equipped with a robust sieve that was inserted under a suspected mine location and lifted. This approach is effective in loose, sandy soil.

Another approach to break up and remove the soil around the mine is to use air or water jets. A US company proposed the Air Spade™ that uses a supersonic air jet to erode the soil surface and move loose particles out of the way. This technology is reported to work well in relatively dry soil conditions, but has difficulty in soils with a strong root structure. Some research centres have also experimented with water jets. The technology is used to cut metal by the nuclear and other industries and has been applied successfully to EOD tasks. It was tried against mine fuses as well. One limitation may be availability of water in some theatres.

ETODS is a system that was developed under the US Humanitarian Demining program. It is a multi-tool tele-operated system that processes the soil within a small area around a suspected mine location. The tools include a vegetation cutter, an Air Spade™, a modified bucket and a manipulator arm. ETODS can also be equipped with a mini-flail. The tools are mounted on a Bobcat class chassis, which is too small to carry sufficient armour to protect an operator, thereby requiring tele-operation.

Although systems like ETODS appear to be effective, deminers have not readily accepted this type of system. It may be necessary to look into social and economic reasons to fully grasp the reasons for the limited deployment of this technology in humanitarian demining. In many countries, demining provides jobs and has become a significant contributor to the local economy. Human nature is such that deminers would reject technology if it means that it would jeopardise their job.

Deminers are more receptive to the introduction of individual tools that enhance their safety and productivity. For example, some of the prodder designs that have been proposed provide an increased standoff, which may be subject to ergonomic or human factor limitations. Other prodder designs are sturdier and may be used as an excavation tool in some cases. New excavation tools with extended length handles are also proposed. In general, the philosophy with these individual tools is to focus on incremental improvements to the tools to make them more effective for the deminer to carry out its tasks in accordance to current procedures. It does not present any radical departure from the current way of doing business.

IMPROVED MUNITIONS DEMOLITION TOOLS

Once a mine or UXO has been located, exposed and identified, it is demolished *in-situ* or it is defused and moved to a remote site for demolition at a later time. Although some Humanitarian Demining organisations have access to good quality explosives such as C4 for their demolition tasks, most still rely on donated high explosives, e.g., 200-gram or 400-gram blocs of TNT. In some theatres, the same organisations are allowed to rummage through recovered munitions to salvage useable explosives and detonators. As a result of these practices, the quality control of the explosives and the reliability of the detonators may be poor, sometimes resulting in misfire

drills that expose deminers to unnecessary additional risks. Several alternatives to the standard demolition bloc have been explored.

Shaped charges have been proposed for the demolition of mines and UXO. The effectiveness of these devices depends on the product [jet velocity x jet diameter], which is a measure of the kinetic energy of the jet. The latter must be sufficient to overcome the critical energy required to initiate detonation in the target, which varies with the explosive type. There is also evidence that distance travelled through the explosive plays a role. If the run is too short, the explosive will not detonate. Furthermore, it is known that the effectiveness of shaped charges degrades with soil overburden, albeit there is little quantitative data about this in the open literature. Note that, in general, humanitarian demining procedures require the uncovering and identification of the munitions, hence a shaped charge should have a clear line of sight to the target.

There exists a variety of commercially available shaped charges that were developed for military applications. The resulting devices produce a high quality, high energy jet but are usually too expensive for humanitarian demining. The perforation charges used in the oil industry to perforate the bottom of wells are very cheap in comparison, but the kinetic energy of their jet is lower and they sometimes fail to initiate detonation in the target. Other factors to consider in selecting a shaped charge device include the method to align the charge and to locate it at a sufficient standoff for complete formation of the jet. The fragmentation of the case should also be considered. Metal cases produce a significant fragmentation hazard. Shaped charges with plastic casings were produced in the US to resolve this problem.

Another alternative that has been proposed is LEXFOAM™, a cap-sensitive nitromethane-based explosive that has more or less the look and consistency of shaving cream. The solution is deployed from pressurised containers that vary in size from a ½ litre can to a truck-mounted system. Demolition is achieved by sympathetic detonation, hence it is important to deploy a sufficient amount of solution fairly close to the target munitions. Obtaining direct surface contact with this product is usually not a problem given its consistency. During a test series in Cambodia, sponsored by the US Humanitarian Demining Program, LEXFOAM™ was found to perform well. However, the containers were pressurised with propane, which was difficult to support in that particular country.

FIXOR™ is another binary liquid explosive similar to LEXFOAM™, but packaged in 400-ml plastic containers. The product is distributed as two plastic containers, one containing a flammable liquid, the other containing an inert white powder. The flammable liquid is red in colour. When the two components are mixed on site just before arming, the product turns to an orange colour, indicating that it is now a high explosive. It is then employed in the same way as the current demolition blocs, thereby requiring less adjustment to existing demining procedures. FIXOR™ performed well in experiments conducted in Canada against a variety of mines and UXO, including mortar and artillery shells.

TEXIT™ is a binary explosive developed by DYNO-NOBEL for the same role as ANFO in commercial mining operations. Two non high explosive components are brought together using a mechanical mixer. The result is explosive slurry that can be poured around the mine or UXO.

The underlying philosophy of products like LEXFOAM™, FIXOR™ and TEXIT™ presents a distinct advantage: they are not high explosives until deployment when a sensitiser is added to the basic mixes. Hence, the components can be shipped independently without an explosive classification, albeit some components are still classified as a flammable liquid. This approach is advantageous in regard to import/export laws, which vary from one country to the next, and to transport regulations.

An alternative to high explosives is burning. This approach can effectively destroy many kinds of munitions, particularly those with plastic or thin metallic coverings. When used against munitions with a thick metal case, it is necessary to precede the burn operation with a step to open the case to allow the insertion of a substance to ignite the explosive fill. Complete burning of the explosive without transition to detonation depends on the amount of confinement of the combustion products and the relative location of primary explosives such as detonators, normally present in the fuse.

One exothermic material proposed to burn munitions is thermite, a mix of sulphur and iron oxide that has long been used to weld train rails. The product can be used in powder form or mixed with a binder to form a solid mix that may be encased and packaged for placement above the target. Ignition of iron oxide requires a substantial heat release that is sometimes obtained through the intermediate burning of another mixture with a lower ignition temperature. Flowing high current in a heating coil initiates the original burning. Thereafter, heat conduction across the target's casing ignites the explosive within and disables the targets.

During a demonstration against AP and AT mines, thermite-based products performed well, but because this neutralization method relies almost exclusively on heat conduction, its effectiveness depends on the target materials and geometry. In isolated cases, the technology was observed to be ineffective when attempting to transmit heat across a region of a mine where the explosive was not in direct contact with the casing. Subsequent attempts with an improved location resulted in the successful destruction of the mine. Another observation is that the detonators should be removed from the mines before using this burn technique, otherwise it is possible to detonate the mine while it still contains a substantial amount of explosive. Even the partial detonation of an AP mine can spread the hot thermite slag around and start unwanted fires. Another point is that there needs to be direct contact between the hot products and the target. Soil is an excellent thermal insulator that will defeat this destruction technique. One definite advantage of this technology is that the components are non-explosive, which makes it easy to transport and store.

FireAnt™ is a product similar to thermite that uses an exothermic reaction to attack target munitions. However, the chemistry is different in that FireAnt™ produces a hot jet that impinges on the target. Oxidation agents can even be added to the chemistry to react with steel cases, the metal used in most munitions. The convective nature of the process makes it easier to erode through the casing and get to the explosive fill when compared to methods that rely primarily on conduction.

Other chemical reaction methods have been studied. For example, a technique was proposed to introduce chemicals in the explosive fill of mines by firing a bullet though the casing and pouring the chemicals to start

burning of detonation of the mine. An alternate concept is to fire a bullet containing the chemicals so that it stops within the mines and starts the reaction. Although interesting, these methods remain at the exploratory stage and have not been deployed in any theatre.

Mechanical Methods may also be used to neutralize and destroy mines and UXO. For example, quick-setting foam was developed in the US that can be sprayed around the fuse mechanism of a mine. Once hardened, it binds to the exposed surfaces of the mine and reduces the probability of accidentally detonating it. A rope can be inserted in the foam to pull out the mine from a safe distance.

Another mechanical means to destroy a mine is to use water jet cutting. A UK company, ALBA, demonstrated the feasibility of destroying exposed mines with a portable water jet system. An abrasive agent must be added to the water for the technique to work. The drawbacks to this system are unit cost and the relatively high water requirement.

A water jet disrupter, like that used by police forces to neutralize Improvised Explosive Devices, could also be effective against some mines. This system uses an explosively driven water jet to penetrate the case of the munitions and take it apart before the explosive train has time to initiate. This technique should be quite successful if the munitions are attacked from a direction different from the one for which its mechanism is designed to operate.

CCMAT CONTRIBUTIONS TO NEUTRALIZATION

From the technologies discussed above, it is seen that many solutions are being proposed to "solve" the humanitarian demining neutralization problem. A large number of players are involved, including private companies and NGOs. The governments from the United States, the Netherlands, Sweden, Germany, Japan and several other countries are directly involved in, or support one or more technical research programs related to humanitarian demining. These efforts cover the whole spectrum of neutralization, i.e., vegetation removal, large area processing, localised area processing, individual tools, etc. Most aspects of the subject are well addressed, and CCMAT should not attempt to duplicate this work.

There are exceptions to the above statement. Canadian companies have proposed several ideas for the development of equipment that could be competitive in the global market. Since part of the CCMAT mandate is to promote suitable commercial products. Ideas that are most probable to succeed should be encouraged, particularly if they are funded through avenues complementary to the CCMAT funds. Some potential candidates include the development of brush cutting implement and mini-flails. Canada is also in an excellent position to develop novel binary explosives that are safer to transport and store. Hence, the role of CCMAT should be to provide technical advice wherever possible, but more importantly, to provide T&E assistance to assess the potential performance of these systems before they are sent in the field. This is particularly true for explosive neutralization technologies that require the use of actual munitions.

With respect to mechanical assistance equipment, the definition of appropriate T&E procedures is a complex issue. The challenges presented to the equipment should be representative of those encountered in a real minefield. This requires an understanding of the threat and the environment

where the machine needs to operate, which varies from theatre to theatre. Furthermore, it is necessary to understand the machine's operating principles and limitations. In general, industry approaches the development of their equipment from intuition, experience and observations. The fundamental principles are rarely studied. Yet, strong dividends often flow from the thorough understanding of why a given machine works. This is an area where CCMAT could contribute because, irrespective of the equipment proposed, the common thread is whether or not the equipment causes the detonation of buried mines and ordnance. This requires an understanding of the interaction between the tool, the environment (be it vegetation or soil) and the mine's fusing mechanism.

There is a need to define T&E procedures that can be applied to a broad range of equipment. Of course, it is reasonable to expect that different procedures will be required to evaluate the effectiveness of vegetation removal equipment as compared to area processing equipment. But in most cases, there will be a need to conduct the tests in a prepared area where target mines and UXO are buried at known locations. In addition, it is necessary to define what parameters will be measured, how the results will be evaluated and what will be the pass/fail criteria. Assistance in development of international test and performance standards should be a CCMAT goal.

Most countries that signed the AP mine ban treaty are faced with the problem that they are politically limited in their capability to use real mines during their tests. This often means that the number of mines used for a test series is small. This can severely limit the scope of the tests and result in data sets that are not statistically significant. The net result is that humanitarian demining organisations will question the accuracy of the results. One can readily see the value that well designed mine surrogates would have. Tests could be carried out with greater scope and with target samples that are statistically significant. To be credible, these surrogate mines must reproduce the mechanical characteristics and fuse action of real mines with a high degree of realism. It is also desirable that they produce some definite indication of whether or not the fuse train was activated during a neutralization operation.

To summarise, the principle contributions that CCMAT to neutralization technologies is to develop T&E procedures and corresponding test equipment. This requires the study of the fundamentals of tool/soil/mine interaction and there is a need to develop a mine analogue that responds to the mechanical inputs in the same way as real mines. The pursuit of these goals can be done while providing T&E support to Canadian industry at the same time.

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CHAPTER FIVE

PROTECTION

PERSONNEL AND EQUIPMENT PROTECTION

This chapter examines the problem of personnel and equipment protection in the context of demining operations. Several factors must be taken into account to select appropriate protection. High-risk scenarios must be identified from the threat and environment with which demining teams must deal. The demining drills, the local infrastructure available to sustain operations and economics must also be considered. The reader is reminded that demining is more than locating and destroying mines within an area, it must also deal with a large amount of UXO and debris.

The material presented in this section is based on mine strike information available to the authors from various Mine Action Centres, e.g., Cambodia and Bosnia. This information is fragmented at best, often incomplete, but it is sufficient to identify typical patterns of mine strike as a function of threat, environment and the activities carried out by victims at the time of accident. Some work is underway in the US and the UK to assemble and analyse more of this type of information, which will fill a void and further help guide the development of protection measures in the future.

The first section examines the overall demining operation to point out where protection is most required. This includes personnel movements from site to site, the manned and unmanned equipment used to support operations, and operations such as level 2 and 3 surveys and clearance where personnel are dismounted, working in the threat area. Data from the field suggest that the highest risk of injury to personnel exist while deminers are dismounted on site. This is not too surprising given that current demining operations rely heavily on manual clearance. Consequently, what the demining community needs the most is suitable and affordable personal protection. This will remain so for the foreseeable future. However, as mechanical assistance equipment gets introduced more and more into demining operations, it is anticipated that additional protection requirements for the operators and the equipment will surface.

The second section of this chapter describes how anti-personnel mines injure people and examines the current state-of-the-art in personal protection. The material is divided into lower body protection and upper body protection, in line with the injury patterns observed in the field. There are noticeable differences in the nature of the injury as a function of the activity that the victim carries out at the time of the accident.

The last section of this chapter outlines areas of technology that require R&D and the associated T&E required to ensure that the protection measures developed meet the needs of the deminers. One area of RDT&E that requires immediate attention is to better understand and quantify the mine injury problem for dismounted personnel. This will in turn help the demining community to select the best commercial equipment in the short term. In the long run, it will help equipment manufacturers to improve the design of their equipment.

OVERALL PROTECTION SCENARIOS

A demining operation potentially faces a broad range of threats, a mix of UXO, anti-tank mines and anti-personnel mines. The UXO threat includes mortars, artillery shells, bombs, sub-munitions, etc. The anti-tank mines are often of the blast or EFP type with pressure or tilt-rod fuses. Anti-personnel mines use blast, fragmentation or both as primary injury mechanisms. In addition to the threat, terrain and tactical placement of the devices also have a strong influence on the protection requirements.

In addition to the above factors, the tasks that deminers must perform, and the environment in which these tasks must be performed, influence the protection requirements. There are four main activities where protection could be required. They are:

- Transport to and from the site by vehicle;
- Protection of the operators of mechanical assistance equipment;
- Protection of robotic equipment; and
- Physical protection for dismounted personnel working on site.

Each area of activity is now examined in more detail.

PERSONNEL TRANSPORT IN VEHICLES

The demining staff needs to move to and from a work site or between work sites. This is often done by medium-weight truck with the staff riding in the cargo box, travelling on roads or cross-country trails. The roads should have been cleared, but the potential always exists that the vehicle will hit a mine. An anti-tank mine would likely cause several casualties, as these vehicles are usually not equipped to resist an AT mine detonation.

Progress has been made recently with respect to understanding the injury mechanisms for personnel riding in a truck [1,2] that encounters a blast mine. This work was in response to the rising number of casualties due to anti-tank mine strikes against UN peacekeeping troops operating in Somalia and the former Republic of Yugoslavia. The injury mechanisms identified include fragmentation, blast, vehicle structural deformation and global acceleration of the vehicle. It is possible to modify the vehicle to protect the occupants against some classes of blast mines, but it requires a judicious choice of materials and the modifications are vehicle-specific. The geometry of the vehicle, its mass and its structure are important factors that influence the design of the protection kit. It is equally important to design the occupant seats and restraining harness so that the force of the explosion does not throw around the occupants. The seat harnesses also protect the occupants during the vehicular accident that normally follows a mine encounter.

If generally accepted humanitarian demining procedures are followed, the probability that a vehicle encounters a mine while travelling on a road is low. As will be seen, there are higher priorities and, for this reason, the scenario of vehicle-mine encounter during staff transport will not be considered any further in this study.

DEMINING EQUIPMENT OPERATORS

Heavy equipment such as flails, brush clearance tractors and excavators, earth tillers, etc. is being introduced more and more into demining operations. Such equipment removes trip wires and overgrowth while softening the soil. It is expected to drastically increase the productivity of demining teams. The equipment operator is placed into a relatively high-risk environment and must be protected against the accidental detonation of a mine or UXO. The exact level of protection is a function of the threat found in theatre.

In general, the large equipment has the weight carrying and power capacity to accept the heavy armour plates required to stop high-energy fragments. Consideration must also be given to isolate the operator from blast and shock. In addition, it is necessary to protect electrical and hydraulic lines to enhance the probability that the equipment will remain operational after an accident.

Ballistic and blast protection requirements against anti-personnel and anti-tank mines, as well as for common UXO, can be established from lethality and survivability data that was developed for the military. There is a need, however, to tailor, assemble and distribute this data for the mines and UXOs commonly found in the field. In keeping with the need for sustainability in a third-world environment, this database should be restricted to easily obtainable and maintainable materials such as mild steel and ballistic glass. The database should clearly indicate the thickness of material required for stopping fragments from the above threats. There is sufficient expertise within industry to handle this work, hence CCMAT does not intend to pursue this matter.

ROBOTIC EQUIPMENT

Besides the fact that it removes the operator from the high-risk zone, the attraction of robotic equipment is that it can be made smaller and lighter. This should ease the burden of maintenance and transport in war-torn countries. By the same token, the smaller size and weight of robotic vehicles reduce their probability of survivability against the detonation of an AT mine or large UXO. But this kind of equipment should fair well against AP mines. The protection measures for robotic equipment are similar to those for heavy equipment. In addition to electrical and hydraulic lines, it is necessary to protect the control electronics, antennas, cameras and other sensors.

DISMOUNTED PERSONNEL WORKING ON-SITE

Current demining operations rely almost exclusively on manual clearance methods. This exposes the on-site dismounted personnel to the greatest risk of injury. Reports from the field indicate that it is useful to classify injuries according to two principal threat types: fragmentation mines and buried blast mines.

Fragmentation mines include stake mines and bounding mines. These devices may contain up to 600 or 700 grams of explosive in a heavy metal case. The explosion generates a significant blast hazard and spreads a large number of fragments that kill or injure individuals within a pre-determined radius. The lethality of the fragments decreases rapidly with distance

because of a combination of air resistance that slows down individual fragments, and because of dispersion, which decreases the probability of a hit. In most cases, the detonation of the device is actuated by trip wire, which also means that mine detonation can happen anywhere around a demining team.

The traditional approach to protect people from mine blast and fragmentation is to load them with layers of ballistic protection and shock absorption materials. To optimise performance, body armour must be judiciously distributed to provide enhanced protection to vital areas such as the head and chest, while lighter weight and more flexible materials protect the extremities. Using this approach, it is feasible to design equipment that gives effective protection for distances greater than 1 or 2 meter from the mine explosion. At close range, the effectiveness of the protective equipment degrades rapidly with distance because of the greater lethality of the fragments combined with the exponential increase of blast overpressure.

Protective clothing was developed in several countries to protect soldiers from ballistic and blast threats. There also are adaptations of bomb disposal suits [3] that were made lighter and more flexible for the mine clearance mission. By and large, this protective equipment is ill adapted to the humanitarian demining scenarios [4]. Adding weight on the body increases the metabolic rate and leads to additional heat load. If not counteracted, it results into physical and mental impairment of the person. The ergonomics of the equipment must also minimise interference to human senses such as hearing, vision, tactility, mobility and flexibility. It soon reaches a practical limit where it interferes with the person's capability to carry out the tasks required, thereby increasing the likelihood of injury.

Exposure to trip wire activated mines occurs primarily during a level 2 survey to define the boundaries of a mine field, or during the early stage of the clearance of an area with overgrowth. Fortunately, the procedures for demining operations ensure a high probability of detecting trip wires and fragmentation mines. Furthermore, it is expected that mechanical assistance equipment will be used in the future to remove vegetation and trip wires. Hopefully, this will reduce the probability of injury to dismounted personnel from fragmentation mines to a negligible level. This leaves the buried blast mine with low metal content as the principle threat. Protective equipment should be designed accordingly.

Accidents involving the detonation of buried blast mines occur either: (i) while walking on the site, (ii) while prodding or (iii) while doing an unsafe procedure or movement. The latter situation should be addressed through procedures and discipline. The other situations are characterised by prevailing patterns of injury. Injury to the lower body is typically the result of a person stepping on a mine while in the upright position. Injury to the upper body is predominant when a person is prodding or attempting to expose a mine.

The quality control issue dictates that manual clearance will continue to be the mainstay of demining for the foreseeable future. Personal protection is - and will remain - one of the highest priorities for deminers. Hence, the remainder of this chapter will describe anti-personnel mine injury in greater detail, examine the state of personal protection technology relating to the blast mine threat and outline directions where research and development is needed to improve the lot of deminers.

BLAST MINE INJURY TO PERSONNEL

The issue of anti-personnel mine injury was examined by a multidisciplinary panel of experts in [5]. Two mine injury scenarios prevail: injury to the lower limbs and injury to the upper body. The first relates to a person walking on a mine and the second to a person detonating a mine while prodding or otherwise contacting the mine. The participants examined the evidence available to them and debated the nature of mine injury mechanisms. From a medical perspective, they agreed that mine injury results from three distinct mechanisms: burns, blast and projectiles. They could not agree on the contribution of each mechanism as a function of scenario and threat, except that the relative contribution from each mechanism depends on the distance from the explosion.

Burns occur because of the extremely high temperature of the explosive gases. The amount of heat generated during a mine explosion depends on several factors, including the depth of burial and the mass of explosive. In general, the likelihood of burns increases with the amount of explosive used. It is also greater if the mine is shallow-buried. Burns are also caused because clothing or surrounding material catch fire. Some articles of clothing are more susceptible to catch fire. The body regions exposed to burns depend on the activity carried out at the time. An individual walking on a buried blast mine is more likely to suffer burns to the lower legs, thighs and groin, while an individual in the prone position may suffer burns to the hands, arms, upper body and face.

Blast injury is complex and caused by many processes. Two regimes can be observed. In the region nearest to the explosion, a strong shock wave and extreme pressures combine to disintegrate soft tissues (muscles, nerves, arteries, etc.) and strip them away from the bones. It results in traumatic amputation and drives foreign materials high up the leg.

Further away from the explosion, the blast wave decays below the threshold where it can strip tissues, but remains sufficiently strong that overpressure can affect air-containing organs such as the ears, lungs and gastro-intestinal (GI) track. The amplitude and the duration of the overpressure both affect the extent of injuries. The ear, with an overpressure threshold around ½ atm, is the most sensitive organ and injury can range from temporary to permanent degradation of hearing. Balance can be affected if the ear injury is severe enough.

Shock transmission through the body can rupture blood vessels at the cell level, cause lesions or rupture organs such as the spleen, liver and brain. Shock propagation in fluid-filled organs may cause cavitation, thereby resulting into local haemorrhages that usually lead to complications within 24 hours from the accident.

If a blast is sufficiently large, it can propel a person, causing injury when the person impacts the ground or surrounding objects. However, the small amount of explosive used in AP blast mines is not sufficient to propel an individual over a significant distance. Instead, it is more common for the force of the explosion to propel objects and debris that injure neighbouring people.

The physiology associated with projectile wounds has been studied extensively. There is similitude in the wound process whether it is caused by a streamlined projectile (*e.g.*, rifle bullet) or a mine fragment. As the

projectile penetrates soft tissues, it forms a temporary cavity that closes soon thereafter. The size of the cavity and its closure are direct functions of the elasticity of the tissues. Some organs, such as the brain and the liver have very little elasticity and, correspondingly, can be destroyed in the process. The penetrating projectile sucks dirt and debris in the wound. The projectile often comes to rest within the body. The wound track has a narrow region of destroyed tissue/bone material surrounded by a varying area of contused tissue that quickly swell. The swelling causes local pressure to exceed that required by the body to supply wound tissue with blood. Without proper blood supply, the tissue dies and greatly increases the risk of infection.

LOWER BODY PROTECTION

One of the most common mine blast injuries is to lower limbs while a person walks. It usually involves all three injury mechanisms, *i.e.*, burns, blast and projectiles. Close contact between the foot and the explosive destroys the foot, launching fragments of boot, dirt and bone upward into surrounding tissues. Injury is often inflicted to the second leg and fragments can damage the crotch and the abdomen. Typical treatment of this type of injury results in amputation, either below the knee, or above the knee. The rehabilitation time lengthens as the amputation occurs higher. Injuries to the abdomen and upper organs can result in complications.

The traditional approach to protect the lower extremities from AP mine blast is to add armour plates in the sole of boots. However, improper design of the armour plate can be detrimental. For example, if the plate is built as a solid piece, it transfers the explosive shock in the form of a stress wave capable of shattering the bones of the foot. The blast also imparts kinetic energy to the plate, driving it upward and thereby amplifying the damage potential. Hence, the geometry of the armour must be selected to deflect as much blast energy as possible. The blast accelerates the armour material upon which the blast pressure acts, but some of this energy can be absorbed in the form of strain, *i.e.*, deformation of another material. This approach usually results in the use of a V-shaped deflector with the apex directed downward, combined with an easily deformed material such as foam or honeycomb.

Various "mine-protected" boots built upon this principle are available commercially. The armour is restricted to the rear portion of the boot to allow proper flexing of the toes and increase comfort. Therefore, the forward portion of the boot is unprotected. In practice, these boots offer effective protection against the blast of up to approximately 25 grams of TNT. For a blast under the armour portion of the boot, injury is not avoided, but the probability of traumatic amputation is reduced significantly in comparison with the same blast against under an unprotected boot. There also exists over-boots that use the same sole and armour as the mine-protected boot, but designed to fit over a standard combat or work boot. If used in combination with a mine-protected boot, it is claimed that protection against up to 50 grams of TNT may be obtained.

The basic drawback of armour plates in the sole of boots is that materials are exposed to extreme pressures that far exceed the limits of current protection materials. Energy absorbing materials fail in this pressure regime because they are destroyed before they have a chance to do their job. This rationale is used by the proponents of alternate foot protection methods based upon the principle of stand-off. The detonation

pressure and temperature of the explosive is of the order of 100,000 atmospheres and 3,000 to 5,000 °C, respectively. As the gas expands, these drop exponentially to values below the material limits. Different devices, or platforms to be more accurate, have been developed or are being proposed to take advantage of stand-off.

One approach is to have the platform resting atop an air-filled bag. In theory, the bag conforms to terrain features and distributes the pressure evenly over the ground, but when dealing with a sharp terrain discontinuity, a pressure point may result into an excessive localised deformation of the bag and a corresponding decrease of the standoff. The platform geometry can also play an important role in regards to transmission of blast loads to the lower leg. The mine explosion yields a rapid expansion of the detonation products accompanied by transient supersonic gas flow. The flow is highly directional, predominantly in the upward direction, with speeds ranging anywhere from 400 to 3000 m/sec depending on depth of burial. Arresting this strong flow results in a significant pressure build-up that propels the platform into the leg. The more the platform traps the flow, the more it increases the acceleration forces to the underside of the foot. The selection of materials also affects shock transmission to the skeleton of the foot. It is therefore still possible that the use of a platform will not prevent an amputation. However, if properly designed, it should greatly reduce the probability of such an occurrence.

Another approach is to mount the platform on legs terminated with soil interface pads. Contact between the legs and the ground occurs outside the projection of the foot on the ground. The underlying assumption is that detonation takes place under a pod, thereby providing more space to vent the detonation products. Such a platform design is not immune to terrain discontinuity. Under some circumstances, it is possible for the bottom of the platform to contact the ground directly and cause a mine detonation. Should this occur, this platform design could result into excessive loading to the bottom the lower leg as previously explained.

Irrespective of the platform concept, the question of how much stand-off is required is open to debate. A variety of factors, such as the type and mass of explosive in the mine, depth-of-burial and soil conditions, can affect the severity of the injury. There is a need to quantify these parameters, present them in a format suitable for engineering purposes, and to relate the corresponding loads to medical consequences.

Another issue that must be addressed is protection of the second leg. The foot in direct contact with the explosion sustains most of the damage. The probability of traumatic amputation of the other foot or leg, due to blast overpressure, is reduced substantially because of its stand-off from the explosion. However, depending on the explosive content of the mine and its depth-of-burial, the second leg remains susceptible to injury from burns and fragments. With respect to burns, the exposure to the hot detonation products lasts only a brief period of time, of the order of 1 to 5 thousandths of a second. Skin burn protection may be obtained from a garment made of a fire-retardant material, *e.g.*, Nomex III ™, that covers the skin. Protection from fragments requires armour materials within the garment to match the threat. Human factor issues that relate to wearing the garment under given environmental conditions and for particular tasks must also be considered.

UPPER BODY PROTECTION

Several injury reports mention that the accident occurred while a deminer was prodding the ground or was exposing a mine. This scenario leads to a broad range of injuries to the hands, arms, chest, neck and face. Traumatic amputation of a hand or fingers is often reported. Burn and fragmentation injuries to the neck, face, and particularly to the eyes, are common. Injury to the groin and legs are not reported as often, but can happen depending on the prodding position adopted by the deminer. At least 5 or 6 prodding position are used. In some theatres, the prone position is adopted. However, this position is not the most comfortable for people that must prod all day long, particularly if one must also contend with bugs and snakes in the area. The prone position also takes more time and energy for a person to get back to a standing position as compared to, say, kneeling. Other advantages of an upright position is that the person can better use their body weight to lean against the prodder and that it offers a better perspective of the terrain being prodded. This is why some deminers prod in the kneeling position, with either one or both knees on the ground. In other theatre, people prefer to squat to prod right in front of them or to one side. Finally, it is reported that some deminers bend over the ground they are prodding. There is little, or no, data to compare the merits and limitations of various prodding positions. Yet, this information is needed to determine if some positions clearly increase the probability and severity of injury. If an optimum prodding position can be identified and broadly adopted, it would greatly help to improve the effectiveness of protective equipment.

Several technologies can be used to protect a deminer that is prodding. They include garments and materials capable of stopping ballistic fragments. These may incorporate shock absorption properties to mitigate blast transmission to the torso. Examples include fragmentation vests, helmets and visors in use with military and police forces. However, it is necessary to consider the environment and tasks that deminers must perform to determine if such commercially available protective equipment is suitable. There are also severe cost constraints imposed on demining organisations, which often cannot afford the cost of protective equipment developed for western forces.

Efforts are underway to develop low-cost, yet effective, protection technology for humanitarian demining [6-9]. These include the development of protection for the groin, abdomen and thorax. There is also work to find lightweight visors and helmets, and to add a deflector on the prodder to shield the hand from direct blast effects.

There are at least three approaches to protect the groin, abdomen and thorax regions. The first is to use a light version of a bomb suit that provides all around protection. However, this solution produces equipment that is too bulky and hot to wear all day long. Furthermore, the capital cost to acquire such equipment exceeds the budget of most humanitarian demining organisations. There is nevertheless a role for such equipment where personnel may be exposed to the threat of fragmentation mines. A second approach is to provide an intermediate level of protection with an ensemble that consists of chaps, a groin protector and a chest protector. The back is given minimal or no protection. This equipment assumes that the threat comes from blast mines that explode either under the foot or directly in front of the deminer. The cost of such an ensemble is lower than for all around protection, but could still exceed the budget of many demining organisations. The third approach, which is also the lowest cost option, is

to use a long bib that protects only the front of the person. It assumes that the threat comes from a mine detonation while a deminer is prodding or exposing a mine.

Protection of the hand and arm is challenging. The hand is often the part of the body that is closest to the explosion. Hence it is exposed to the most severe blast conditions and as such, is more prone to traumatic amputation. It has been proposed to add a lightweight blast deflector to the prodders and hand tools used by deminers. The trick is to make the deflector large enough to protect the hand, but of a geometry and size small enough to minimise force transmission from the blast. Polycarbonate appears to be the material of choice for this application. It is relatively cheap and can be moulded to the appropriate shape in country.

Protection of the neck, face and head is a high priority. Current protection measures include the use of goggles as well as partial and full-face visors. The ballistic performance of goggle materials is often reported to be inadequate for the job, but this requires further investigation. The principal limitation of goggles is that they are only intended to protect the eyes. Injuries to the rest of the face are often reported in cases where a deminer was wearing only goggles. Partial visors suffer of the same limitation as goggles, *i.e.*, they do not cover the full face. The geometry of a partial visor is also prone to trap the force of the blast and to not remain in place to perform its intended function. Full face visors offer the best chance to limit the severity of injury from a blast mine, provided it is properly designed for functionality and comfort, and that it has acceptable ballistic performance.

Polycarbonate is often used as visor material [10], which is not necessarily the most appropriate choice for field use. It is easily scratched, which degrades the visual acuity of the deminer and hence compromises his or her ability to do the job safely. Under some climatic conditions, the visor can also fog. Deminers have been known not to use the visor if it impedes their vision. Anti-scratch coatings have been proposed as a remedy to this situation, but other materials should also be considered. There is also a debate whether the thickness of the material, 5-mm in most cases, offers sufficient ballistic protection. The stopping power of this visor material is often quoted to be between 250 and 285 m/sec for a 17 grain standard fragment, but it is important here to consider the nature of the fragmentation. Mines that have a thick casing made of a brittle material, *e.g.*, bakelite for a PMN mine, produce highly energetic fragments. Other sources of fragmentation are the prodder and excavating tools used by deminers. If these cause a mine detonation, the portion of the tool closest to the explosion is destroyed and can generate fragments of varying shape and mass. There is therefore a need to better characterise the range of fragments a deminer could be exposed to, and to create a list of materials with suitable ballistic, cost and manufacturing characteristics

RDT&E GAPS AND CHALLENGES

From the above discussion, it is seen that providing effective protection against landmines and UXOs is a difficult problem. Protection is required for a broad range of threats and scenarios, but they cannot all be addressed. It is necessary to focus our efforts where the need is greatest. A close look at current accident statistics dictates that at this time, the greatest need is in the area of personal protective equipment for use during manual clearance tasks. Several kinds of equipment have been proposed, but

there is little, if any, solid experimental data to support various claims about their protection level. This issue should be addressed as quickly as possible. There is also an immediate need to examine the prodding positions used by demining organisations to find out if particular positions offer clear advantages in regards to comfort and safety. Adopting a specified type of position would help to improve the effectiveness of protective equipment.

In the longer term, there is a need to develop a detailed understanding of the injury mechanisms themselves. There exists significant knowledge gaps in that regard. By developing an adequate understanding of the injury mechanisms, it will be possible to improve the performance of protective equipment. New equipment must also be evaluated according to internationally accepted standards. Work is required to develop these standards in parallel with the corresponding test equipment, test procedures and injury assessment criteria.

The design of protective equipment should be done with due regards to human factor issues to achieve a balance between comfort, functionality and protection. Furthermore, this should be done within the financial and environmental framework of humanitarian demining organisations. Finally, there is a constant need for better materials that can be used to manufacture protective equipment.

PERFORMANCE OF EXISTING PERSONAL PROTECTIVE EQUIPMENT

A number of manufacturers offer protective equipment, from mine blast boots to helmets and visors. Legs, groin and chest protective equipment is also becoming available. Deminers would like to know if and how much this equipment improves their protection. Testing the performance of this equipment poses a serious challenge, first because deminers face a broad range of threats and scenarios in real life, but also because the threat itself, particularly the fragmentation threat, is not well defined. This is further complicated by the fact that recognised test standards and procedures for humanitarian demining protective equipment are not yet firmly established. In spite of these constraints, common sense can be exercised to test some equipment.

The performance of foot protection equipment (blast boots and platforms) against blast mines can be measured using a gauge apparatus, *e.g.*, by measuring the strain and kinetic energy imparted to a metal column. The results cannot be correlated directly to human injury at this time, but they provide a measure of relative performance. In due time, a calibration for such tests will be developed so that the performance of the equipment can be related to a probability of specific medical outcome.

A first order evaluation of protective equipment for the remainder of the body, from the upper legs to the head, can be done. It may be necessary to design separate tests to gauge performance against mine blast and against fragmentation. Again, there is a need to develop appropriate test procedures, test equipment and corresponding injury assessment criteria (to be discussed below). With appropriate time and resources, these goals will be achieved. In the mean time, a relative measure of the effectiveness of upper body protective equipment can be obtained using measurements such as shock attenuation across the equipment and their ability to stop fragments. With respect to the latter, an effort should be made to characterise the fragmentation associated with some blast mines and the destruction of prodders and excavating tools.

INJURY SUSCEPTIBILITY FOR VARIOUS PRODDING POSITIONS

There is no authoritative assessment of the probability of injury for the different prodding positions. Military doctrines call for the prone position, but this is often for covert operations where personnel may be exposed to enemy fire. The setting for humanitarian demining is vastly different. The operations are overt and no one is shooting at the personnel. Therefore, there may be reasons, other than comfort, to adopt a more upright position such as kneeling or squatting. From the point of view of blast protection, increasing the distance between the explosion and the vital organs is advantageous. However, this must be balanced against exposing the same organs to a greater fragmentation hazard, including environmental as well as secondary fragments from broken tools.

In the short term, it is proposed to experimentally assess the merits of various prodding positions with anthropomorphic manikins. These would be instrumented to measure the shock and forces imparted by the blast of mines with different explosive content. Ear pressure can be measured too. By recording the event on high-speed film, the intensity and duration of the fireball can be measured and the likelihood of burns can be estimated. The high-speed films also provide limited information about the fragmentation hazard. These tests can be conducted in parallel with the testing of upper body protective equipment to see how the equipment reacts. Valuable information may be gained in regards to the ability of face shield and goggles to remain in place under such an extreme environment.

DETAILED INJURY MECHANISMS

The experimental tests proposed above address some of the immediate needs of the humanitarian demining community. There is also a need for a longer-term approach that requires conducting research over a number of years. The aim is to develop a detailed understanding of mine blast injury mechanisms and to take advantage of this knowledge in designing protective equipment in the future. It is believed that significant progress can be made within three to four years.

One of the first priorities is to gather details about mine accidents during demining operations and to organise this information in a comprehensive database. Some of the details required include a description of the activities and position of the victim at the time of accident, a description of the soil and environmental conditions, the mine being worked upon, the injuries suffered and the medical outcome. The US Humanitarian Demining Program is sponsoring the development of such a database [11], which should be completed by the end of 1999. Scientific and medical researchers can then use this database to correlate and validate the results from fundamental and applied research.

As explained before, a mine explosion results in a broad range of injuries. Very close to the explosion, the exact process of traumatic amputation, most common to foot injuries, is not fully understood. There is a need to study the propagation of shock waves in bones and soft tissue and the corresponding damage. Animal legs (*e.g.*, pigs and cattle) can be used to support fundamental investigations, but they are poor substitutes for the human anatomy. Human cadavers provide the right anatomy, but bone strength and muscle response may change after death. Moreover, such testing is a highly emotional subject with deep moral and ethical implications.

Scientists of the Defence Scientific and Technical Organisation of Australia have proposed a reasonable alternative to human cadaver tests. They are developing a Frangible Synthetic Leg (FSL). The core of the FSL consists of plastic reproductions of human bones with approximately the same material strength. The bones are attached together with simulated cartilage and the assembly is set into ballistic gelatine representing the muscles. The combination is encased in a thin leather skin that simulates human skin. Artificial arteries can also be added within the gelatine and the bones can be instrumented with regular strain gauges. Accelerometers or load cells can be embedded just about anywhere in the FSL.

The bones are dyed with x-ray sensitive compound so that they can show up on medical x-ray diagnostics tools. Furthermore, the use of bones in their anatomically correct position presents the inherent advantage that bone breaks can potentially be reproduced. The entire approach has been designed so that both scientific and medical personnel can work with the data. Although this method is still at the experimental stage, it is very promising. Much work remains to calibrate the FSL against injuries to a live human.

Canada is part of an international team that will work with Australia to further develop and calibrate the FSL. Through CCMAT, Canada proposes to sponsor a series of experiments where the FSL would be the principal diagnostic tool to evaluate the effectiveness of foot protection equipment. These experiments could be conducted in relatively short term and the results would be compared to those with the mechanical gauge apparatus and the US-led injury database. The FSL experiments would likely involve a mix of scientific and medical staff and access to a CATSCAN machine.

It is also proposed to develop numerical simulation tools in parallel with the FSL. This technology has reached a level of maturity where it adds significantly to the understanding of phenomena like shock and stress wave propagation within the FSL. The necessary computer codes already exist, but geometrical models of the bones, ligaments, gelatine and skin need to be developed. Material properties also need to be measured and incorporated in the model. Furthermore, it is necessary to develop an appropriate simulation of the input forces generated by the explosion of a mine buried in soil. This work requires a combination of numerical and tuned experiments. The complete simulation can then be validated against experimental results.

Numerical simulation is also useful to study how the transient flow field created by the explosion of a mine removes goggles and visors from the face of a victim. It is would also be useful to study the forces transmitted to the head of a person, which depend on the shape and area projected by the equipment into the path of the flow. The information is useful to improve facial protection equipment. The same numerical techniques coupled with simplified models of human body kinematics can be applied to the study of how explosion forces interact with the whole body. These computations would complement the anthropomorphic manikin experiments to determine the merits of various prodding positions.

TEST AND EVALUATION STANDARDS

There is a long-term requirement to standardise the test procedures to evaluate the performance of protective equipment. The FSL will provide detailed information about injury susceptibility, but each device can only be used once and it requires a specialised team of scientific and medical staff to analyse the data. Therefore, it is desirable to develop test devices and diagnostics that can be used more than once and that require a less specialised team. This is the approach used by the automotive industry to quantify car safety with their Anthropomorphic Test Devices (ATD), better known as crash test dummies. Instrumentation is used in the ATD to measure physical quantities such as acceleration, forces and bending moments. The measurements are then related to a broad range of injury susceptibility, e.g., likelihood of neck and head injury. This knowledge base was developed over several years by correlating ATD physical measurements with the injury patterns of people involved in actual car accidents. A similar approach can be adopted to assess blast injuries.

A blast ATD would play an important role in the development of protective equipment. However, it must be recognised that it has its limitations. First, it assumes that some level of physical protection has been achieved to the point that traumatic amputation can be avoided and that deep penetrating fragments can be stopped. If not, other test methods and devices must be used, e.g., the FSL for traumatic amputation and witness panels or plywood cut-outs for fragmentation. An ATD is best suited to assess the probability of injury for things like lower leg bone breaks or shock transmission to some vital organs. The probability of eardrum rupture and skin burns can also be measured.

The development of a blast ATD requires adapting several components from the automotive ATD to an explosive shock environment. The principle differences are the rate of application of the forces as well as the type of forces that come into play. During a car accident, the whole body is subjected to sudden inertial forces applied over a time frame of tens of milliseconds. Soon after, it hits surrounding objects, which results in localised impacts leading to blunt trauma. In a mine explosion, the body is exposed to an intense shock and a transient high-speed flow over a time frame of about one tenth of a millisecond, i.e. about two orders of magnitude faster than for a car accident. Furthermore, the intense pressure and temperature near the explosion far exceed the body strength, resulting in local destruction of bones and tissue. The mine explosion generally results in more severe body load conditions than for the automotive accident.

Because of the difference in the shock environment, the blast ATD instrumentation must be mounted differently and have generally a greater measuring range. Some of the manikin parts must also be designed to be more rugged. For example, this is the case for the lower leg modules that must measure the amplitude of shock transmission as well as the bending, shear and torsion forces applied to the bones. Injury to the head and face may be estimated from global head acceleration, neck bending moments and neck shear forces. The probability of eardrum rupture is obtained from ear over pressure measurements and skin burns are estimated from heat transmission measurements.

The development of a blast ATD is considered to be medium risk. Other countries like Australia and the UK have initiated such developments, hence some of the issues have already been addressed. In most cases, it draws from

the existing automotive ATD technology. Further work requires proper tuning of the instrumentation to eliminate ringing and other undesirable characteristics. It is best to do this in parallel with experiments. Once the instrumentation performs satisfactorily, the measurements need to be correlated with the FSL data and a mine injury database.

The fragment distributions from anti-personnel fragmentation mines have been characterised for the military. Countries that signed the Ottawa II treaty to ban anti-personnel land mines have an obligation to declassify and distribute this data for the mines that they manufactured. No more work is required for these particular devices. On the other hand, there is a requirement to characterise the fragmentation generated by the casing of blast mines and from demining tools. Blast mines were not designed to injure via fragmentation, hence there was never a need to characterise their fragmentation. Standard methods to measure fragmentation include flash screens and flash x-ray photography. Arena tests with real weapons using witness plates and wood manikins can give useful information if performed on a properly instrumented range. Once reasonable distributions of fragment mass and velocity have been obtained, there may be a need to test protection materials for their effectiveness against these new fragments. With equivalent fragments, it would be possible to perform material tests in a laboratory environment. Full protective ensembles could be tested later using a blast ATD.

HUMAN FACTORS

The introduction of protective equipment to the field takes some effort to convince deminers that it provides them with the protection they require while not hindering their ability to perform the job safely. This is why some attention must be given to human factors. Irrespective of the protection some piece of equipment provides, human nature is such that people will wear it only if it is comfortable, or if it makes them "look good". Other practical issues must also be addressed. It is important not to hinder the ability of the person wearing the equipment to perform their tasks. Human senses such as vision, hearing, tactility and mobility must be preserved as much as possible. Of course, some trade-off will likely be required to balance the ability of performing tasks with protection. Another important consideration is that new drills and hand tools may be required along with the introduction of protective equipment.

The above statements point to the importance of looking at the complete picture when designing mine protection equipment. All parameters affecting mission performance must be put in the balance and their effect weighted against the overall mission goals. One should ask the question: "*Can these people, with their training, under these conditions, with this equipment, perform these tasks to the acceptable standard?*" The following Venn diagram expresses this principle.

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11. Private communication with Mr. Andy Smith, U.K., January 1999.

CHAPTER SIX

MEDICAL/VICTIM ASSISTANCE

INTRODUCTION

The biggest challenges facing medical/victim assistance are:

a. to be truly useful and to provide real medical/victim assistance value in context for mine affected countries;

b. to provide focused, relevant aid for the specific needs of humanitarian demining;

c. to provide assistance in a timely, sensitive and caring manner; and,

d. to provide sensible and supportable aid capable of functioning effectively in underdeveloped areas of the world.

The primary objectives of medical/victim assistance are to reduce morbidity and mortality. Reduction of morbidity, or minimizing the effects of the mine injury, is primarily concerned with preservation of tissue and function of limbs, organs, etc.

LIMITATIONS AND CONSTRAINTS

The CCMAT program regarding medical and victim assistance issues is limited by resources and focussed by the clear intention to have an early practical impact. In addition, the requirement for rigid medical scrutiny and a lengthy approval process before implementation of a medical procedure or introduction of new medical equipment limits the work to investigation of "off the shelf" technologies, adaptation of existing technologies, and consideration of medical procedures/equipment in a very advanced stage of development. CCMAT is not staffed with medical practitioners and significant use would have to be made of outside resources. This would spend funds better spent in other CCMAT areas where new technologies can have a significant impact. These factors placed severe limitations on the scope of work in the medical/victim assistance field that could be undertaken under CCMAT auspices.

POTENTIAL R&D FIELDS

In spite of the imposed constraints, there are several avenues available to CCMAT that can be exploited to make a contribution to humanitarian demining. CCMAT staff can conduct or obtain a survey of injury profiles to determine the specific injuries encountered in mine accidents. Using this they can identify specific procedures and/or equipment that must be available for treatment. This study and the data obtained would also be mutually beneficial for R&D related to protection technologies where vulnerabilities can be identified and protective devices provided for mine action personnel. The advice of medical personnel familiar with mine action requirements will be an important information source. DRES personnel also have access to the Canadian Forces Medical Group for detailed advice on field treatment and evacuation methods. Injury modelling is an important aspect of

R&D into medical treatment and protection. The results of this work can provide important input into the development of surrogate test elements which will simulate human response to a mine accident. This would greatly accelerate and assist in the development of protection standards and development of protective ensembles for deminers. The injury modelling could possibly be used to facilitate studies of treatment/diagnostic evaluation. It could also be used as an aid for realistic training of those responsible for treatment of mine casualties.

There are a number of medical technologies which have recently been developed and could have a beneficial effect on mine casualty treatment. These include advances in wound dressings, in antiinfective barriers and in simple technologies to provide sterile water and medical devices, applicators for antiinfectives, and blood clotting aids. These will be examined as possible supplements to existing medical kits. The medical kits themselves will be critically examined for potential shortfalls and/or upgrading their contents. Good medical kits and standards have already been produced by selected militaries and by the demining community and the emphasis will be on incremental improvements where possible and practical.

New scanning technologies can offer some improvement to diagnostics. One of the most serious consequences of a mine accident is the introduction of infective foreign objects such as dirt and fragments into a wound. Technologies which can detect and locate those foreign objects would greatly assist the treatment of mine casualties.

The detailed and comprehensive study of the treatment of mine injuries has recently seen renewed interest in the medical community, mainly due to the needs of the mine action community. There has been new techniques developed in mine victim care that can mitigate the effects of the injuries and preserve post injury function of limbs. These strategies must be given as wide a circulation as possible within the mine action community and this is another function that CCMAT could undertake using its information dissemination capabilities.

SUMMARY

In summary, the provision of a large, comprehensive program in medical/victim assistance is severely limited by the medical regulatory process, time and resource constraints. There are some niche areas where CCMAT could provide some benefit to the demining community. Examples are:

a. recommended improvements or upgrades to existing medical kits and/or medical kit standards;

b. search out potential medical technologies which can be practically and beneficially applied to the demining scenario;

c. conduct R&D into the development of injury modelling and surrogates for limbs, etc., which can facilitate provision of improved protection equipment and standards; and

d. assist in the dissemination of information relating to the treatment of mine casualties and make the medical community more aware of the specific needs of mine injury treatment.

CHAPTER SEVEN

ENABLING TECHNOLOGIES

INTRODUCTION

Enabling technologies is a label for those technologies that support, facilitate, or enhance the tasks of demining but are not specifically part of the protection, detection, or neutralization technologies. Rather, they are technologies that have the potential to increase productivity in demining by allowing improvements in demining methods to be safely and reliably implemented. They may also provide increased accuracy and improved safety on demining tasks.

SCOPE OF ENABLING TECHNOLOGIES

The scope of Enabling Technologies for the purposes of CCMAT R&D will be limited to technologies that directly enhance the detection, neutralization, and protection tasks. This subject could span a wide range of technologies from batteries that power handheld detectors, through the internal electronics of detectors, to materials used in equipment fabrication. However, given the limited mandate of CCMAT it was decided to limit the investigation to a relatively narrow range of technologies that had the most potential for enhancing demining operations in general.

The technologies considered tend to be ones that allow the demining process to be mechanized, or that allow multiple detectors to be used in combination to enhance detection and reduce false alarms. These techniques, while adding to the capital cost of the equipment used in mine action, have the potential to dramatically increase the clearance rate and ultimately reduce the total cost of clearing a given area [Ref 1].

GEOGRAPHIC INFORMATION SYSTEMS (GIS)

Geographic Information Systems are computer programs for registration and presentation of geographically correlated data. They provide all of the information available from conventional paper maps, adding the capability to add and display data that overlays the basic map. Examples of overlay data include the location of known or suspected minefields, detected landmines, or cleared areas. Both the underlying map data and the overlay data can be manipulated in many ways that aid in planning mine action operations and assessing the performance or priorities of a mine action centre. All of the demining action centres throughout the world have identified some form of GIS as being essential during survey levels 1, 2, and 3 of demining, maintenance of accurate clearance records, task planning, and reporting of progress. To date, each mine action centre has adopted a GIS and, independently, added custom functions to form a Demining Information Management System (DIMS) specific to their operation. There is no standard system or software in the demining community. This has lead to little in the way of economies in procurement, exchange of information between centres, reporting of information to central agencies such as the UN and Geneva International Centre for Humanitarian Demining (GICHD), or common training of DIMS users/operators. GICHD is currently leading an attempt to adopt a common set of demining functions and apply it to a single, commercial, GIS [Ref 2]. CCMAT supports this initiative and proposes to maintain a liaison with GICHD

to contribute to the functional requirements of the DIMS and to support and coordinate its adoption as a standard.

DATA FUSION

Data fusion is a technique that combines multiple data streams in order to derive more information from the combined stream than is possible from any, or all, of the streams when considered individually. Data fusion is essential to exploit the true capacity of multi-sensor detection systems [Ref 3]. To operate, the technique requires that the data from each point on the ground be collected from the individual detectors and analyzed together. The data may be analyzed one point at a time, or with all of the data from the local region being analyzed in consideration of its value and its position. In the event that the detectors can be mounted in such a way that they "look" at the same piece of ground as the detector is moved over the ground this can be straightforward; however, in general, this requires that the data be spatially registered.

Spatial registration requires that the detector position is measured as well as its output. The position measurement may be relative to some arbitrary point on the ground, or be an absolute measurement with respect to a geographic reference frame as in a latitude, longitude and elevation position. In either case, the ability to use data fusion is dependent on having highly accurate position data for each detector as it is moved.

Data fusion techniques, in and of themselves, are highly dependent on the detector types that are being combined. An understanding of the physical phenomena being measured by each detector is required in order to implement an effective fusion process. Given the diverse nature of the detection phenomena that have been proposed for mine detection, data fusion for mine detection is not amenable to a general solution. Hence, CCMAT sponsorship of research and development in this area will be limited to that incorporated in specific detection systems. However, the requirement for position measurement to allow data fusion will be considered in a later section.

MECHANIZATION AND AUTOMATION

Introducing mechanized equipment into the demining process has tremendous potential for improving clearance speed [Ref 4,5]. Operations such as vegetation clearance, prior to detection, are tremendously time consuming in manual demining and expose the personnel to serious risk of injury from undetected mines that may be disturbed in the process. Mechanized vegetation cutters or "harvesters" can greatly speed this process if the damage to the machine and risk to the operator associated with mine strikes can be controlled. Further some detection techniques proposed, including most that utilize multiple detectors, are not possible or realistic for man portable implementations. In some instances the detector apparatus or supporting equipment is simply too large, in others, the detection process requires that the data be spatially registered to allow the detector response to be processed as a function of its position and response. In the latter case, position measurement with a hand held detector is extremely difficult and prone to error, reducing the potential effectiveness of the technique. Mounting these types of detectors on vehicles allows for the implementation of higher accuracy position measurement and could also allow for use of automated scanning of single detectors, where appropriate.

As noted above, mechanized equipment is likely subject to mine strikes. While the equipment can be designed to minimize the damage and to reduce repair costs, attempting to shield the equipment operator from any chance of injury is difficult. Utilizing remote control to remove the operator from the equipment is the surest way of minimizing his risk. Simple remote control, where the operator is simply moved away from the equipment and operates it at a distance is unworkable in most applications as the operator has an inadequate view of the area near the vehicle. Hence, tele-operation is required, in which video cameras onboard the vehicle transmit imagery back to the control point. This allows the operator to observe the vehicle workspace despite being removed from it.

Tele-operation is well established in explosive ordnance detection (EOD) and hazardous materials handling "robots"; however, the available equipment reflects limited design innovation and sophistication due to the small market size and specialized nature of these roles. This results in equipment that has high operator workload and requires significant training for operation. Further, the equipment tends to be poorly integrated and inadequately documented, requiring a high degree of technical expertise on the part of the operators to maintain the equipment and troubleshoot faults. While the mine action market is no larger and no less specialized, it is often conducted in very remote areas and will be operated by local, non-technically trained, staff that will have minimal opportunity for training on operation or repair and maintenance of the equipment. Mine actions centres can not support the level of technical and operational training demanded by conventional EOD solutions.

This leads to a requirement for more technically sophisticated or "intelligent" tele-operation systems that can minimize the operator workload and training requirements. Concurrently, the implementation of this equipment must be simplified to minimize the complexity and training requirements for repair and maintenance of the equipment. CCMAT proposes to support the refinement of existing tele-operation equipment, developed by the Defence Research Establishment Suffield (DRES) for military roles, to meet these goals. This equipment will be designed to make it as generic as possible, allowing the same system to be used to equip a broad variety of mechanized de-mining equipment.

The equipment developed will be capable of minimizing operator workload through simplifying control actions and providing some pre-programmed manoeuvres for repetitive tasks. Operator supervision and action to recognize and avoid obstacles or to control the vehicle payload would still be required. Fully autonomous, or "robotic" operation, where the control system would measure and react to the environment to complete a task without operator interaction, is seen as involving too high of a technical risk and too great of a system complexity. There may be limited instances where it may be cost effective, or technically required [Ref 6], to add specific control mechanisms that react to a measurement of the environment; however, a more general robotic functionality will not be pursued.

To demonstrate the utility of intelligent tele-operation in the specific context of mine action, the equipment developed will be used to control two demonstrator vehicles. These will be outfitted with a vegetation cutter and a scanning metal detector. Neither demonstrator will be developed to an operational level, rather they will be used to illustrate the improved functionality of the approach over more simple remote control systems. This will allow the use of available, off-the-shelf vehicles and payloads (the

vegetation cutter and detector) that may not be fully appropriate for actual field use.

POSITION MEASUREMENT

As noted above, the ability to accurately measure the position of a detector is a requirement for some scenarios involving multiple detectors or advanced detection data processing. Accurate position measurement is also useful in situations where an automated neutralization system may be available, allowing the neutralization system to be placed over a suspected target without the aid of external markers. Advanced differential Global Positioning System (DGPS) systems are commercially available that allow for extremely accurate position measurement (on the order of 2 cm error), unfortunately these systems only measure the position of their associated antenna. Determining the position of a detector or other apparatus attached to the vehicle requires more information than DGPS can provide alone, specifically the orientation of the vehicle; its heading (relative to North), and its "pitch" and "roll" (relative to a horizontal plane). Further, it is desirable to have a positioning system that maintains accuracy for short periods when DGPS measurements may not be available. This can occur when trees, other vegetation, or terrain obscure the line of sight between the DGPS receiver and the satellite based transmitters it uses for position determination.

The conventional method for achieving these goals would be to use an integrated navigation system (INS) where the position measurements from the DGPS are merged with those from an inertial measurement unit (IMU) and a measurement of the vehicle speed (often using an accessory un-driven wheel - or "fifth wheel"). Many commercial systems have been developed based on these principles, however they are designed for different applications and do not meet the mine action requirement. The requirements for navigation systems in the commercial marketplace tend to focus on mass market applications with relatively low precision; agricultural applications where heading is of secondary importance to position; or military applications where DGPS is not applicable.

Given the lack of commercial demand, relatively little work has been done attempting to achieve high levels of attitude accuracy in an INS configuration that includes DGPS. While this is readily possible when utilizing a high accuracy IMU and a fifth wheel [Ref 7], such a system is likely unaffordable for most mine action systems. Component costs, driven by the IMU cost, would be well over 100 K CAD for each system and fifth wheels are notoriously delicate and difficult to maintain. Reducing the cost and complexity of such a system might be possible through reducing the quality of the IMU used and abandoning the fifth wheel, however, maintaining the accuracy required will require new techniques to compensate for IMU errors. Motion estimates from DGPS will be used to estimate and compensate for these errors, however the potential accuracy achievable is unknown. This approach has significant promise, in that the navigation system cost could be reduced to one-quarter to one third of more conventional approaches. Unfortunately it has commensurate technical risk. Balancing the need for affordable, accurate position measurement to implement some of the more promising detection methods and the moderate technical risk, CCMAT proposes to implement a research program to investigate whether an INS based on DGPS and a moderate accuracy IMU can meet the mine action requirement. Funds will be allocated for development of integrated prototypes, but they will not be committed unless the research results are promising.

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CHAPTER EIGHT

TEST AND EVALUATION

INTRODUCTION

The primary objective of test and evaluation (T&E) is to verify that an equipment under test will perform the function for which it was designed. This means that it will perform in accordance with the manufacturer claims and that it will perform in the field in a satisfactory manner, given the conditions that prevail in the operational environment.

T&E can be performed under controlled conditions in a laboratory. Such testing will control all the variables to the extent possible in order to isolate the parameter being tested from the influence of other parameters that may have an effect on the results. For example, in order to quantify the sensitivity of a metal detector, its response to standardized conductive targets under conditions of controlled temperature, humidity, soil type, depth, etc. might be measured and the responses from various detectors measured against one another. Such testing must be done in order to be objective and quantitative and would constitute a primary part of the T&E process for equipment.

Success in such laboratory testing does not, however, provide confidence that the equipment will necessarily perform well in practice in the field. In the field the conditions are not, in general, controllable. It has been the experience with equipments offered for use in humanitarian demining that they may fail, under these practical conditions, to perform as well as might be expected from the results of controlled laboratory testing. Because of this experience, it is necessary to evaluate the performance of equipments in actual operational environments.

EXPECTATIONS OF DEMINING USERS

Potential users of an equipment need the confidence that it will perform to its specifications in the environment in which it will be applied. A vital component of that required performance is the ability of the equipment to operate in the threat environment posed by the mines likely to be encountered. There is no substitute in the deminer's eyes for testing done against the actual mines found in a mine-affected country. Beyond this, the potential user needs to know if the equipment is supportable in his/her environment.

It must be borne in mind that equipments have, in the past, been introduced into service where all these factors have not been adequately assessed. The result was abandonment of the equipment, even though it promised to perform well according to testing done in controlled environments.

Because of these user's expectations, it is an integral and necessary part of the T&E process to evaluate these supportability factors as well as performance factors. To do this, it will be necessary to perform test and evaluation of candidate equipments in real or near real scenarios. Necessarily, these tests will not be rigorous and often not quantitative. The purpose of such testing is to identify otherwise unforeseen difficulties in employing the equipment that would not emerge from laboratory testing

alone. Field testing would not, in general, be undertaken until rigorous laboratory testing had been done and an assessment of quantitative laboratory measurements was in hand.

PRACTICAL TESTING SCENARIOS

In order to evaluate the suitability of an equipment, practical scenarios must also be provided. These can be of two types:

a. Test ranges with realistic minefields constructed on them. An example of such a facility is the emplaced minefield at the Canadian Centre for Mine Action Technology (CCMAT), where typical mines are placed and left in the ground for extended periods (years) allowing trials against a realistic target set.

b. In country trials where the equipment can be tested in the actual environment where it will eventually be applied. An example of such practical testing is the Technology Development Cell at the Cambodian Mine Action Centre, where there is the capability to do practical testing of candidate demining equipment under the conditions where it would be used.

A representative, but not necessarily complete, list of general equipment attributes that require evaluation in order to assess the utility of an equipment in practical use is:

a. ergonomic and human factors considerations;

b. sensitivity to vegetation and surface irregularities;

c. ruggedness in practical applications;

d. survivability in a mine environment;

e. transportability when relying on existing infrastructure such as bridges, etc.;

f. in-field maintenance feasibility;

g. ease of and requirement for field calibration and adjustment;

h. susceptibility to manufacturer's unit to unit variations;

i. availability of manufacturer support;

j. supply of power and consumables;

k. battery duty cycle as a function of local conditions; and,

l. ease of training and realism/effectiveness of the training.

Specific attributes may be tested on a particular category of equipment. For example, an electronic metal detector would require performance tests to assess attributes such as:

a. required signal integration time;

b. false alarm sensitivity and rejection in practical environments;

c. sensitivity to ambient noise in practical environments;

d. drift of equipment performance as a function of time and environmental conditions; and,

e. sensitivity to variations between operators for conditions such as variable sweep rate or distance held above the ground surface.

Ideally, an in-field laboratory would be available for every theatre of operations. This is clearly not supportable within the budgets of most mine action agencies or CCMAT. In practice, it will be necessary to have sites available where representative conditions can be reproduced for most of the expected environmental variations. It is usual to have sites that replicate conditions of hot, cold, humid and arid climatic conditions, and soils with a variation of grain size, composition and compaction. In humanitarian demining, other variables may be more important such as vegetation type and density, surface water conditions, surface irregularities, and the effect of previous land use. All of these factors present challenges to replicating actual conditions in mine affected countries.

The primary consideration in practical testing is to identify unforeseen difficulties in the operational application of equipments. The fundamental laboratory assessments are assumed to be done and found satisfactory. The most effective way to accomplish "operational testing" is to put the equipment in the hands of those who would ultimately use it and to note their experiences as they use it. This will quickly identify deficiencies in the design that place the user in awkward or tiring working attitudes. It will also identify variances in the efficiency of the equipment when operated by different individuals and suggest best practices in the way the equipment is to be used. Human factors issues can only reliably be identified through the use of the equipment under conditions that approximate those anticipated in actual operations. The areas likely to contribute test and evaluation exercises are equipments for detection, neutralization, disposal and human protection - the primary functions of demining.

The availability of an in-field laboratory in a given theatre of operations is, therefore, an enormous advantage. The site in Cambodia has already proven its utility in that operation. Similar facilities should be encouraged whenever possible, however, the reality is that this will not generally be attainable. There are three possible alternatives. The first is to replicate the environmental conditions of the mine affected countries at the site where the scientific/technical testing will be conducted. The second is to utilize test facilities in other locations that are already constructed and more closely equate to the conditions of a mine-affected country. This could be implemented through existing agreements between laboratories or through agencies such as the International T&E Program. (See below.) The third alternative is to conduct the trials in the mine affected country using existing facilities and making up any technical shortfalls by bringing the required equipment and T&E personnel to the site.

INTERNATIONAL TEST AND EVALUATION PROGRAM

ITEP is a United States/European Union initiative of participating nations to provide international cooperation in Test and Evaluation (T&E),

and the timely sharing of technological data and information which is strongly beneficial to global mine action. The mission of ITEP is to "provide for the efficient generation, collection and distribution of objective, scientifically-based test and evaluation data on Humanitarian Demining equipment, systems, processes and methods". Goals for the organization are to collect, generate and distribute scientifically objective data and information enabling humanitarian demining stakeholders to make better decisions; and to earn credibility through reproducible tests and timely, transparent global information flow. (Reference 1)

The mission and goals of ITEP are very similar to those of CCMAT. Therefore it was natural for CCMAT to take a major participant role in the ITEP. ITEP is in the process of organizing itself, and being a significant international effort, must be endorsed by the participating national governments. In an effort to make a meaningful contribution until the ITEP is officially formed, some of the participating countries have decided to engage in a number of "voluntary activities" which will result in some collaborative T&E taking place immediately. The most concrete example of this is the testing of performance of a wide range of handheld mine detectors, with active participation from the Netherlands, United Kingdom, United States and Canada.

The major contributions that CCMAT can make to ITEP are T&E in the fields of detection, neutralization and protection technologies. T&E facilities and procedures are already in an advanced state of development and are being expanded to provide a comprehensive T&E capability in those areas. It is felt that provision of these facilities, test personnel, and information exchange on test protocol and procedures will be the most valued and largest input from CCMAT to ITEP. ITEP has also recognized the need and benefit of conducting T&E and providing advice to demining agencies in the actual mine-affected countries. DRES has played a lead role in this type of testing in countries such as Cambodia and Bosnia. It is anticipated that this activity will be continued under the auspices of both CCMAT and ITEP.

Many of the ITEP program elements are a long way from realization. Due to the limited mandate of CCMAT i.e., March 2003, CCMAT must be prepared to meet national T&E requirements very quickly and then CCMAT can pass on the T&E results to ITEP when they are thought to be beneficial. ITEP will be informed of our trial plans and active participation of other countries in CCMAT trials will be encouraged. As ITEP comes on line, CCMAT will provide support to the ITEP organization on an as required basis within the capabilities and resource limitations of CCMAT.

T&E FACILITIES AVAILABLE TO CCMAT

In order to identify potential shortfalls in T&E facilities, an inventory of existing DRES countermine facilities was conducted. This inventory was conducted for the three main areas of humanitarian demining where T&E would be required i.e., detection, neutralization and protection. The results of the inventory are described in the following paragraphs. In addition, facilities, which had to be modified or newly constructed to meet the CCMAT T&E requirements for humanitarian demining, are identified.

GENERAL SITE DESCRIPTION

Although Canada has other defence establishments where mine detector test and evaluation trials can be carried out, in this submission we will restrict ourselves to the testing facilities available at the Defence Research Establishment Suffield (DRES) as these will be the most likely ones to be offered to the International Pilot Project on Technology Co-operation. DRES is situated in Western Canada, near Medicine Hat, Alberta. There are daily commercial airline flights between Calgary, Alberta and Medicine Hat. Medicine Hat is 300 km southeast of Calgary, connected by a 4-lane highway and DRES is 50 km northwest of Medicine Hat. The 30-year mean climatic data for the area are:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temp. Max (C)	-8	-3	2	12	19	23	27	26	20	14	4	-3
Temp. Min (C)	-19	-14	-10	-2	4	9	12	11	5	0	-8	-14
Rain (mm)	1	1	1	13	37	66	33	40	32	8	2	1
Snow (cm)	22	17	14	16	2	0	0	0	2	7	14	19
Wind Spd.(k/h)	16	17	18	20	20	19	18	17	18	19	18	18
Wind direct.	W	SW	SW	SW	SW	W	W	SW	SW	SW	SW	SW
Sun (hrs)	98	126	180	210	278	286	351	306	208	185	122	88

Table 1: 30 Year Mean Climatic Data

DRES has fully equipped modern research facilities with utilities, computing facilities, sophisticated electronic measurement equipment, machine shops, etc. What follows is a description of some of the existing and planned facilities at DRES which will be applicable to landmine detector test and evaluation. All test ranges are located on the DRES Experimental Proving Ground (EPG) which has controlled access. Some of the facilities are not close to utilities, but temporary arrangement for power, water, communication can be made.

DETECTION FACILITIES

NON-METALLIC LABORATORY

The Non-Metallic Laboratory is an all-weather, unique foam building which due to its non-conductive, non-magnetic construction can be used to make very low noise magnetic and low frequency electromagnetic measurements (Figure 8-1). The building is hemispherical in shape with 12 m base diameter. Sophisticated measurements equipment and mechanical positioning systems for targets and detectors are available. This building has been used for testing and evaluation of both handheld detectors and vehicle-width arrays.

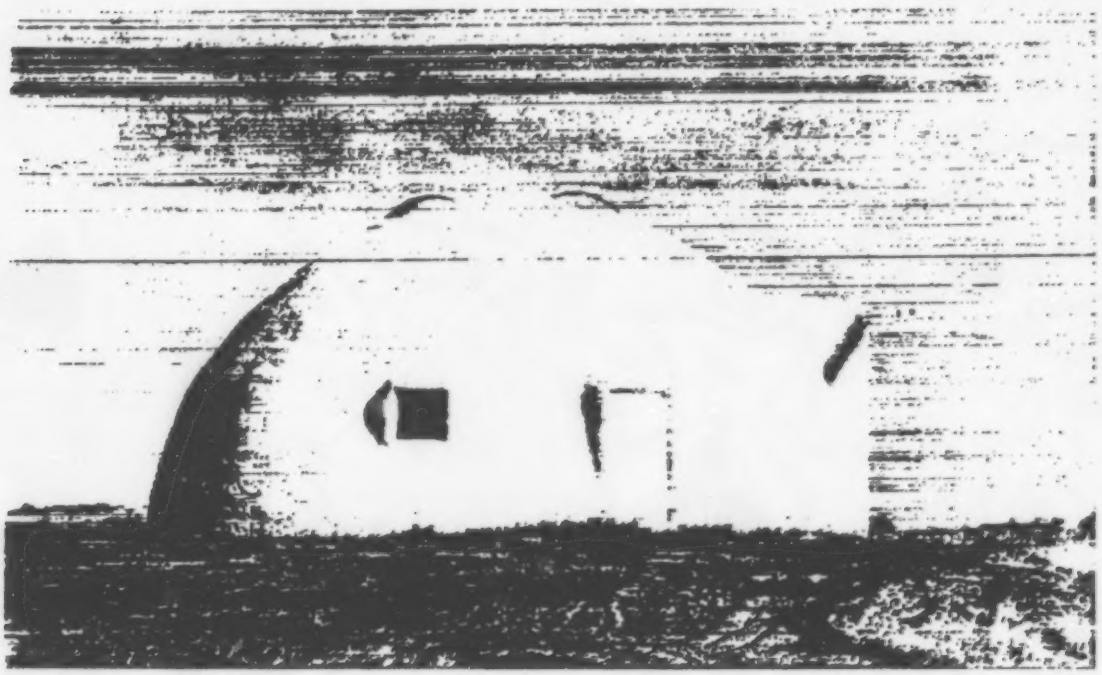

Figure 8-1: The Non-Metallic Laboratory

MINE PEN ENCLOSURE

The Mine Pen Enclosure was specially constructed for the Improved Landmine Detection Project. A plan view and an aerial photo of the Mine Pen are shown in Figure 8-2 and Figure 8-3 respectively. It is a 260m by 340m barb wire topped 8' high chain link fenced area located near field support buildings. It is close to electrical power and convenient road access. It incorporates a one kilometre gravel road along the fence which surrounds a large field containing various soil and vegetation types which include dirt, gravel, asphalt, short grass, long grass, and weeds. Thus it is easy to introduce small test sections, as needed, to provide desired conditions. The Mine Pen already contains many landmines, some of which have been buried since Fall 1995. Although the facility was initially designed to experiment with vehicle mounted systems, it is being used for airborne imaging trials and is suitable for testing almost any landmine detector system, including handheld, in a realistic scenario. Major additions to this facility are planned as described later.

Figure 8-3: Aerial Photo of the Mine Pen Area

Building 15 Area. The Building 15 area is a large 1.2 km x 1.2 km fire guard protection template which contains several field support buildings and facilities. Provided with electrical power and convenient road access, the Building 15 area, also known as the Building 15 complex, can support many activities. The Mine Pen Enclosure and the Non-metallic building are contained within this area.

Hickey Storage Compound. The Hickey Storage Compound is a small 60 m by 70 m chain link fenced area with a sand and gravel road running inside the perimeter. Located approximately 10 km northeast of the DRES HQ area and at least 3 km from any major access roads. It is considered to be remotely located. The site has been actively used by the Improved Landmine Detection Project and currently contains several landmines which have been buried, in the road and in the area inside the road perimeter, since Fall 1994.

Other Sites at DRE Suffield. The EPG and Suffield Training Area cover over 2500 square kilometres and can support many activities. Various areas of land can be set aside for long term experimental setups.

PLANNED ADDITION TO DETECTION FIELD FACILITIES

Additions to DRES Facilities are planned under the auspices of the newly formed Canadian Centre for Mine Action Technologies (CCMAT). These specialized facilities briefly described below are expected to be constructed by Summer 2000. These additions were necessary to provide a variety of test conditions which more closely approximate realistic demining scenarios and increased emphasis on detection of anti-personnel mines.

Figure 8-4 gives a general layout of the planned specialized anti-personnel landmine detection facility which is to be attached to the existing Mine Pen Area already discussed. Provision of a 6 km water pipeline and electrical power commenced in March 1999.

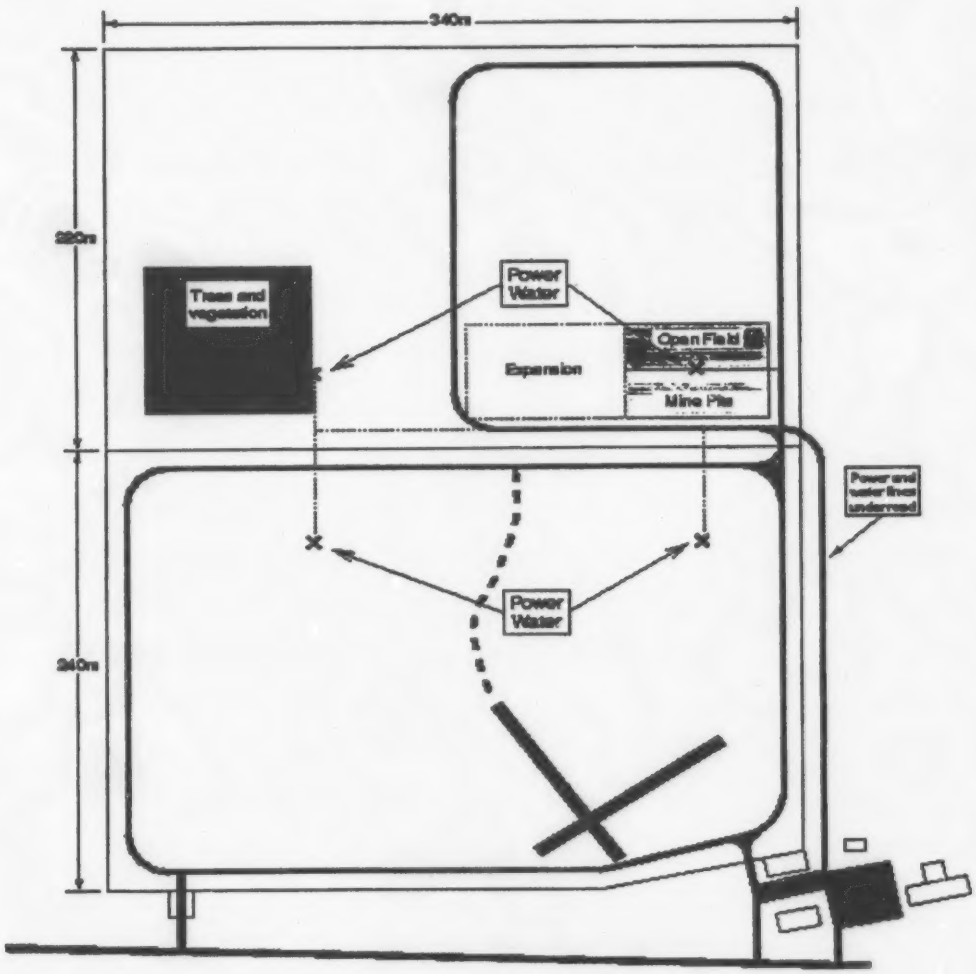

Figure 8-4: General Plan View of Addition to the Mine Pen Area.

It shows the two special areas where the vegetative cover will be modified. The large area located at the bottom left of the grown trees and heavy vegetation. Water would be provided from an above ground timed sprinkler system. The second area is located at the bottom right of the top penned area ("Open Field"/"Mine Pit Area"). In the "Open Field" section short grasses and natural prairie would be cultivated and watered using an above ground timed sprinkler system. The section labelled "Mine Pit Area", has been designated to hold soil pits which are open-bottom boxes with concrete walls constructed into the ground. Different types of soil can be put in the pits as desired. The pits are arranged such that covers can be conveniently moved from one structure to another. Also, expansion is possible by locating more pits to the West. Figure 8-5 is a more detailed view of the area located at the bottom right of the top penned area. Figure 8-6 shows a detailed view of a "Mine Pit", which will be constructed of non-metallic and non-conductive material, will have a movable cover and can be filled and emptied by heavy equipment. The covers used may be constructed using conventional material since they will be moved before any testing. Relative humidity, soil moisture, ambient and ground temperature will be automatically monitored 25 hours a day in both open and covered soil pits.

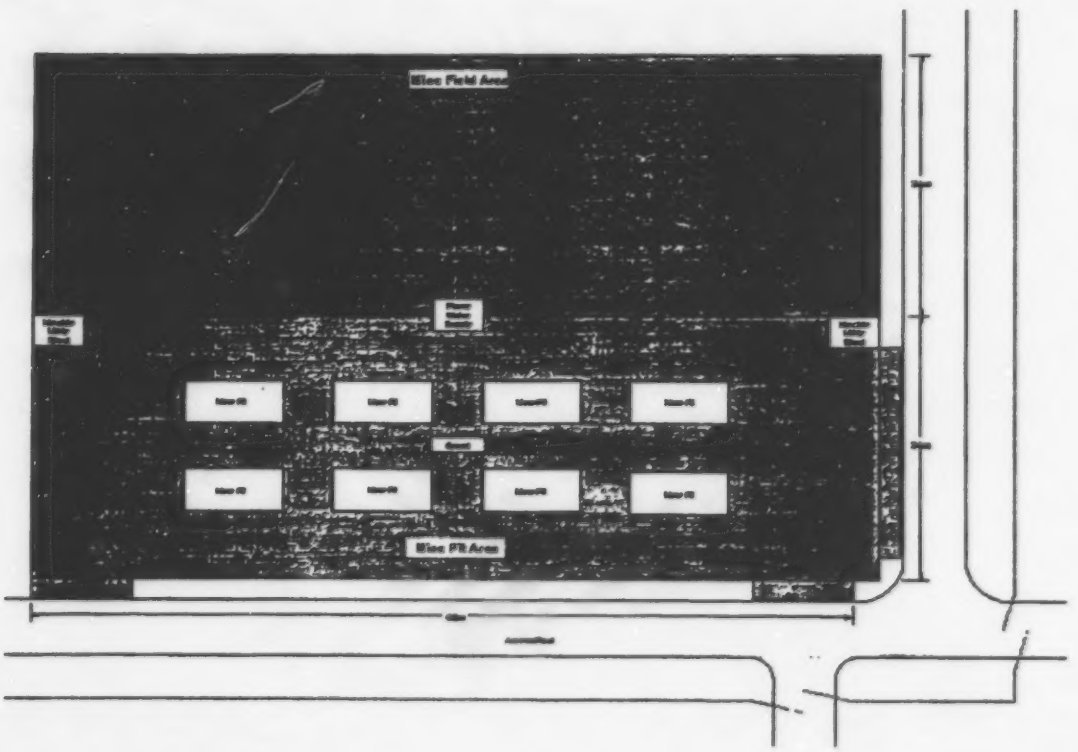

Figure 8-5: Detail of a Test Area

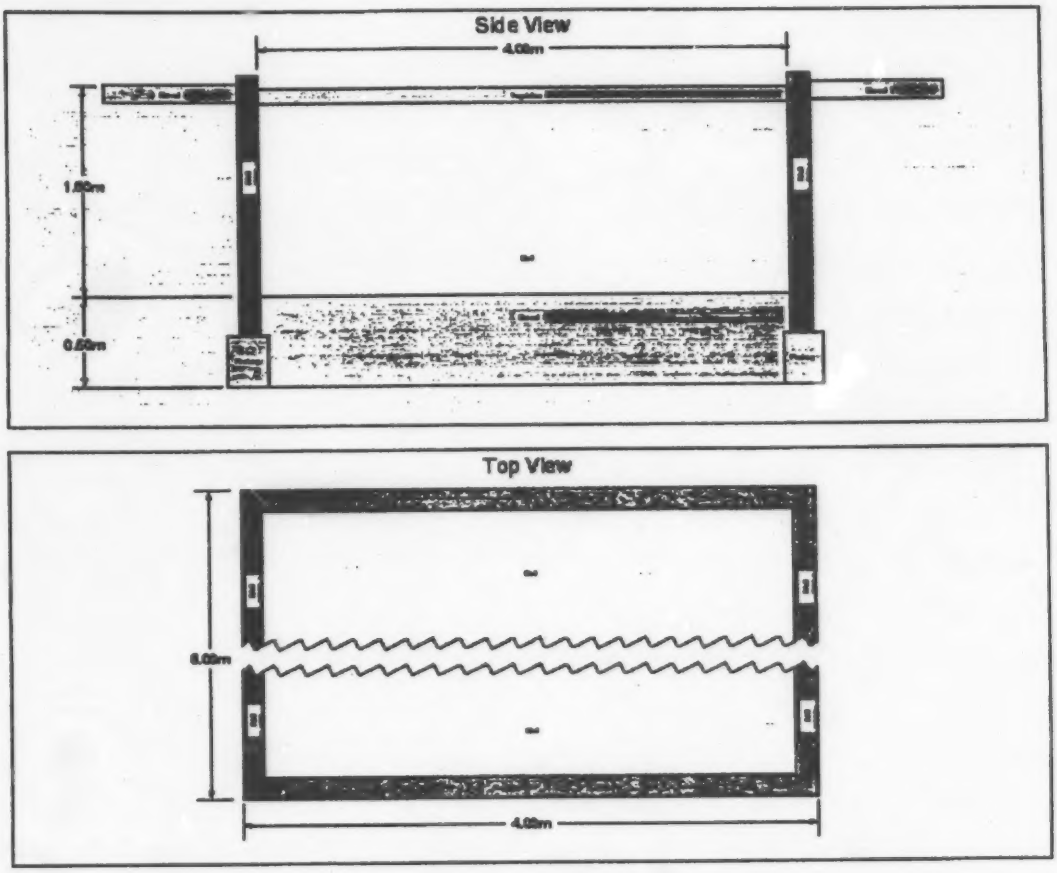

Figure 8-6: A Typical 4m by 8m Landmine Pit Constructed Without Metal or Conductive Components

As well, when fully operational, some of the mine pits will be enclosed in greenhouse-like building(s), taking care to minimize interference from any metal in the structure. The ultimate goal is to have facilities where various environments including soil and vegetation can be simulated.

DETECTION TARGETS

DRES has available the following targets and mines:

a. DRES standard targets. These selected small metal pieces (8) are routinely used for DRES experiments and they have been used in detector evaluation trials in Bosnia and Cambodia.

b. Two sets of US standard targets made by VSE, Inc.

c. One set of MILTRA mine surrogates.

d. An assortment of live mines both AT and AP, including those found most commonly in the Former Yugoslavia. Examples are: PMA-1,2 and 3; TMA-3,4 and 5; TMRP-6.

PROTECTION/NEUTRALIZATION TEST FACILITIES

The Mine Effects Site. The Mine Effects Site, located on the Experimental Proving Ground (EPG), is a unique facility for R&D and test and evaluation. Originally developed by the Defence Research Establishment Suffield (DRES) to support its program in military countermine R&D, the site will also be used by the Canadian Centre for Mine Action Technologies (CCMAT) and its contractors to evaluate low cost, sustainable technologies for humanitarian demining.

At the Mine Effects Site, explosives can be used to simulate mine blast effects in a controlled manner. Situated on the site are various test rigs which are instrumented to identify and quantify the physics of mine blast. These measurements are used to develop and validate computer models that predict the effects of mine blast on structures and human tissue. The site is also used to test and evaluate personal protective equipment and mine clearance technologies proposed for humanitarian demining operations.

PROTECTION/NEUTRALIZATION

INDIVIDUAL FACILITIES

Vehicle Test Area. An Area of prepared ground, including a short segment of gravel road, has been set aside for vehicle trials. Instrumented landmines (charge removed) and other devices, buried in the ground, record the pressure exerted by a vehicle as a function of soil conditions, depth of burial and other parameters.

The Large Scale Test Facility. This structure (see Figure 8-7) measures the blast effects from charge sizes up to 2 kg (C4 equivalent). These relatively large charges are buried in a "huge, oversized bucket of sand" and targets are attached to the superstructure. Two large force transducers are built into this superstructure to record the total load imparted by the charge. Depending on the nature of the target, which will vary in shape and other characteristics, smaller transducers and other instruments can be sited on the superstructure to measure local blast effects. Experimental variables include soil conditions (in the bucket), stand-off distance, depth of burial, charge size and type of explosive.

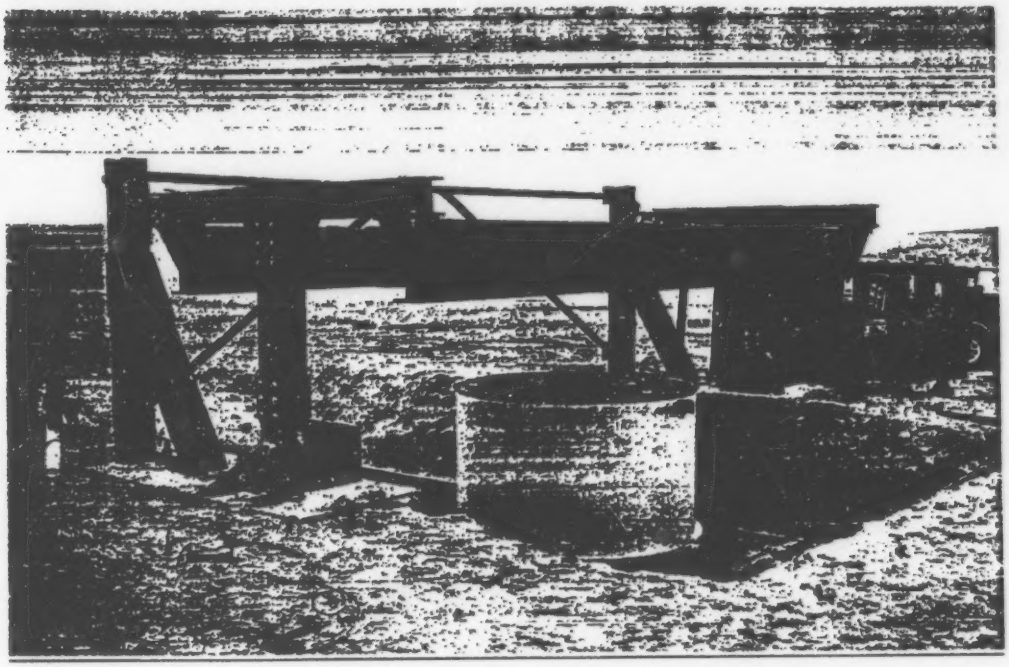

Figure 8-7: Large Scale Test Facility

Near Field Blast Effects Facility. This structure (see Figure 8-8) measures the blast effects from smaller charges (up to 100 g of C4 equivalent). These charges are placed in a bucket of sand and targets are attached to the superstructure. The instrumentation on this rig collects detailed quantitative information on mine blast, as opposed to integrated load values, and the data are used to investigate the physics of mine explosions and to develop and validate predictive models. As with the large scale facility, the experimental variables include soil conditions (in the bucket), stand-off distance, depth of burial, charge size and type of explosive.

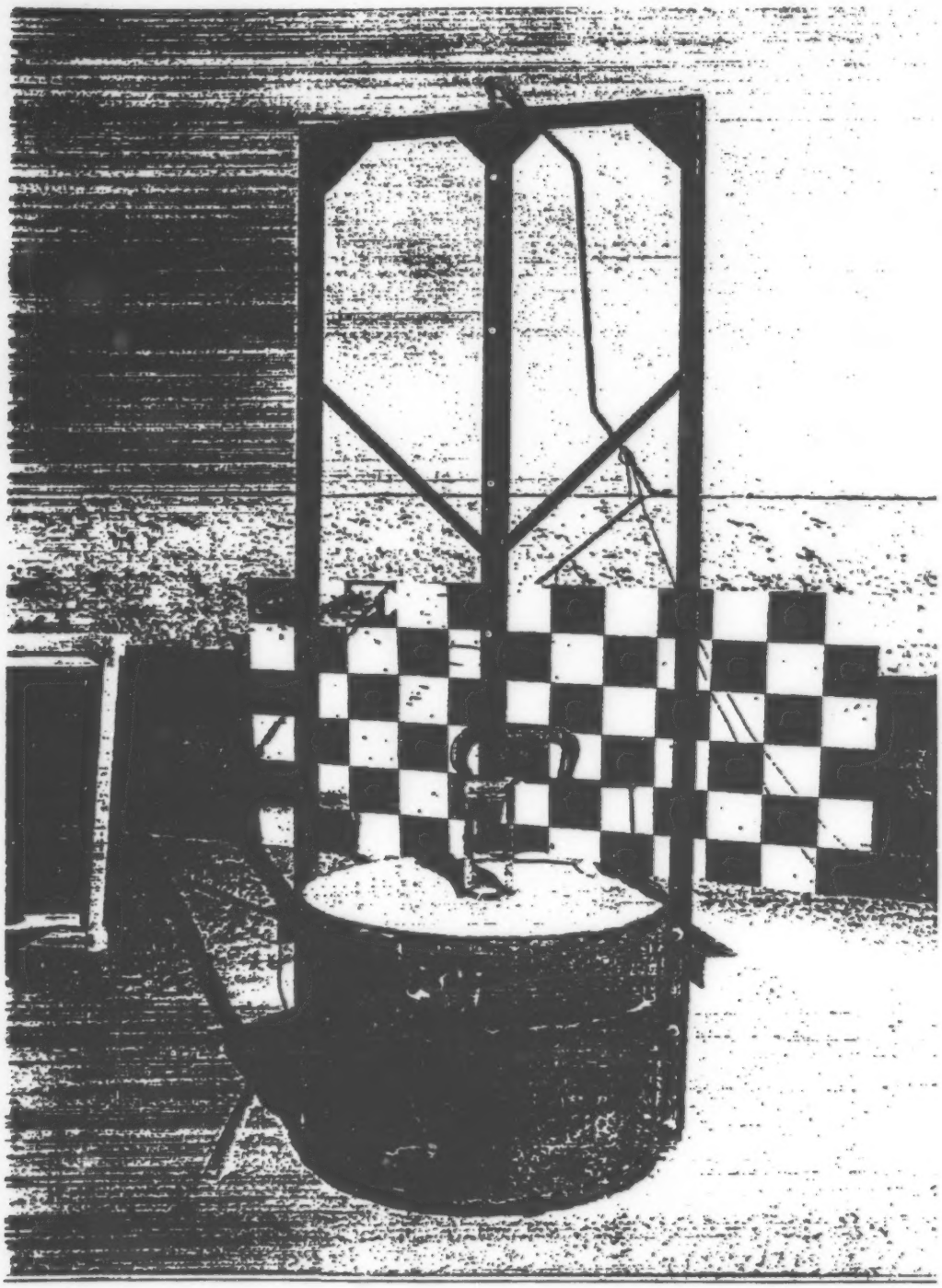

Figure 8-8: Near Field Blast Effects Facility

The Horizontal ballistic Pendulum. This device (see Figure 8-9) performs a similar function to the Large Scale Facility in that it measures the total load imparted to the target by the charge; other instrumentation is required to separate the bulk load into its components. The unique feature of the pendulum is its portability which means it can be moved to a different site to take advantage of special soil conditions. The experimental variables are soil conditions, stand-off distance, depth of burial, charge size (up to 1 kg) and type of explosive.

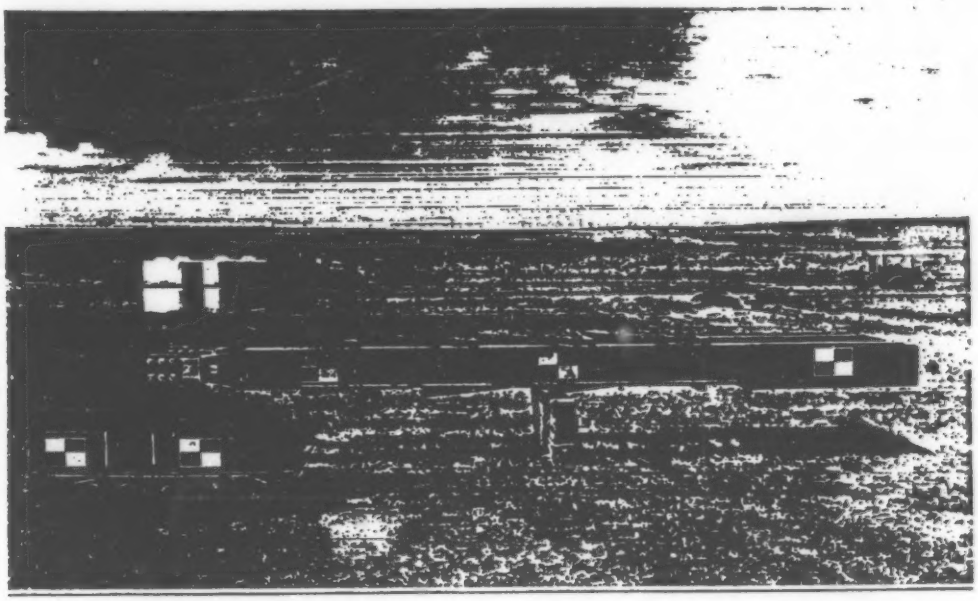

Figure 8-9: Horizontal Ballistic Pendulum

The Surrogate Leg Test Facility. This facility (see Figure 8-10) measures the probability of injury to the lower leg from anti-personnel blast mines. It is also used to evaluate protective clothing and equipment for the lower leg, such as mine boots. Built into the metal leg are strain gauges and accelerometers. The former measures bending of the leg, indicating the possibility of bones breaking due to flailing, and the latter measures the shock transmitted to the leg and the chance that bones will shatter. A linear transducer at the top of the rig provides a measure of vertical displacement and the total energy imparted to the leg by the charge.

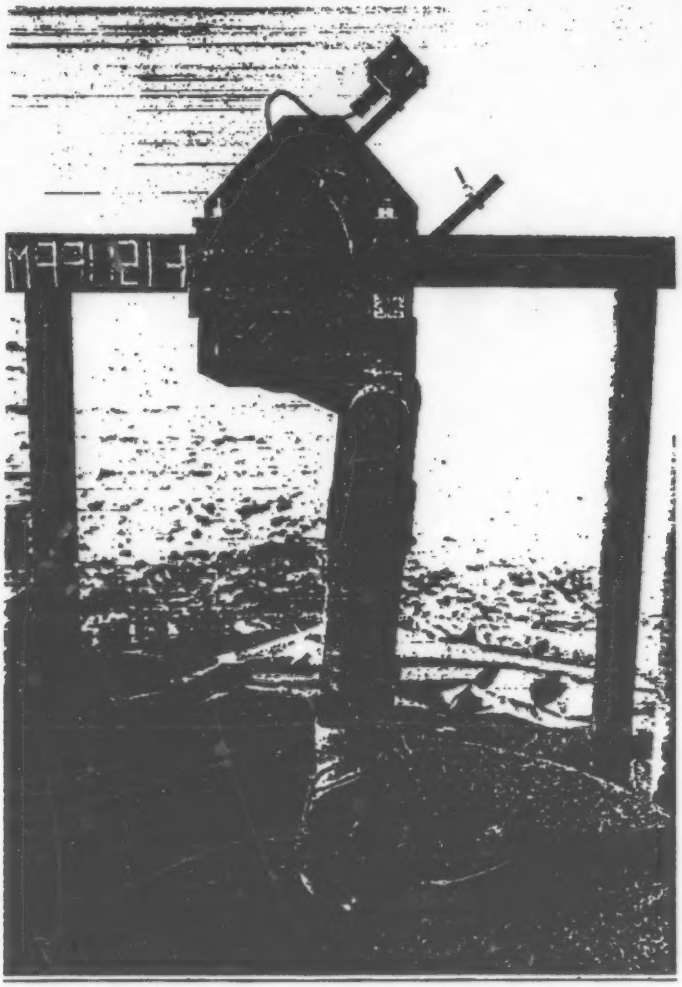

Figure 8-10: Surrogate Leg Test Facility

Central Instrument and Control Building. From this building, explosions at the test facilities can be triggered and recorded on video tape. The video cameras and instruments at the individual facilities are connected by underground cable to the control building where the data undergoes reduction and some preliminary analysis. Since this building is heated and the Suffield area is known for mild winters, the Mine Effects Site can be operated almost year-round.

PLANNED ADDITIONS TO MINE EFFECT SITE FACILITIES

Plans for the Mine Effects Site include an additional area of prepared ground set aside for testing mechanical assistance devices proposed for preconditioning ground in older minefields. Surrogate mines, which closely simulate the real thing, will be developed to make this test area one of the most sophisticated facilities anywhere. It is also intended that the

surrogate leg will evolve into a full manikin and will be complemented by technology that replicates blast effects on human tissue.

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CHAPTER NINE

ASSESSMENT

1. In order to determine which technologies should be investigated under the CCMAT umbrella, it is necessary to assess each available technology. We will follow the general assessment methodology used in [1]. That assessment was carried out to determine which technology areas would be suitable for DRDB long term research into detection for countermine operations. The guidelines for assessment in this document have been modified to reflect the differences between the requirements of humanitarian de-mining and those of countermine.

ASSESSMENT GUIDELINES

To arrive at the ratings which follow, assessments were carried out by the authors, based on the reviews as detailed above, the authors' familiarity with foreign programs and their experience in countermine technologies. In spite of the wide range of expertise involved, it is recognized that the requirement to predict future progress, such as research achievements and development costs, will make the assessments somewhat subjective. In order to keep assessment sheets to one page per technology, it is impossible to provide on each sheet all the reasoning and supporting evidence that led to the ratings. It is suggested that readers should read the respective chapters, and, if possible, the chapter references, prior to attempting to form their own opinions on the assessments. After an initial assessment and culling by the authors, only technologies which have sufficient promise to warrant future R&D have been included below. Each technology's assessment consists of a rating table, three narrative items pertinent to the assessment and recommendations for R&D. The four step rating scale for the table is from very poor to very good. The rating scales and scope of the assessment items follow.

a. Time - This is the time to demonstrate the proof of concept or clearly show that the techrology is not feasible for small AP mines, such as the PMN.
Very poor = > 10 years.
Poor = 5-10 years.
Good = 2-5 years.
Very good = < 2 years.

b. Human Resources/Cost - This includes both personnel and time required to develop a working prototype system. It is recognized that often time and personnel can be traded off, however, there is a minimum effort necessary to sustain most technologies.
Very poor = Human resources and cost exceed CCMAT budget constraints.
Very good = Human resources and cost within CCMAT budget constraints.

c. Likelihood of Success - This is the probability of developing a working prototype taking into account technological feasibility, expected budgetary constraints and availability of competing technologies. Where the existing literature is uncertain, assessments were deliberately judged on the side of optimism until recommended feasibility studies have shown otherwise. The

technologies ratings have taken into account suitability to be combined with other technologies.
Very poor = Not possible.
Very good = Excellent potential.

d. DRDB R&D Capability - This refers to in-house expertise and lab facilities.
Very poor = No expertise or facilities.
Very good = Leading edge R&D could be conducted in-house.

e. Cdn External R&D Capability - This includes Canadian industry, universities and other government laboratories.
Very poor = No expertise or facilities.
Very good = Leading edge R&D could be conducted.

f. Capital Cost - This is the expected total one-time cost of implementing a fielded system.
Very poor = Greater than a major weapons system procurement.
Very good = Similar to a small systems procurement.

g. O&M Cost - This includes all post-fielding costs of manning, maintaining, repairing and training. Logistics burden, such as replenishment of expendable materials, is also considered.
Very poor = Greater than that required for a major weapons system.
Very good = Similar to or less than that required for a small system.

h. Overall Rating - Risk and benefit assessments are formed from a subjective average of the ratings of the previous categories also taking into account the narrative comments. R&D time, human resources/cost and likelihood of success have been weighted more highly than other categories.

i. Research and Development Potential - This describes specific areas where research is required to address the problem. It also describes the degree of maturity of the technology.

j. Canadian Experience - This includes previous research done on the technology with respect to countermine applications or closely related problems. It also includes experience and expertise in technology areas which are relevant but have not been directly applied to demining scenarios.

k. Relevance to Humanitarian Demining - Assuming the technology might be feasible, this item discusses the practical constraints on how it could be used in humanitarian de-mining operations.

l. Recommendation - This describes what R&D can be done in the technology area to achieve its usefulness in a humanitarian de-mining role. The three main criteria for recommending future R&D are that if it is novel technology, it must have the potential to lead to significant improvements over existing approaches; if it is previously tried technology, there must be good reasons to assume that previous failures can be overcome; and if it is being thoroughly researched in other countries, there must be compelling reasons to initiate a research program under CCMAT.

DETECTION TECHNOLOGIES

Electromagnetic Induction

	Very Poor	Poor	Good	Very Good
R&D				
Time				X
Human Resources/Cost				X
Likelihood of Success			X	
DRDB R&D Capability				X
Cdn External R&D Capability			X	
Implementation				
Capital Cost				X
O&M Cost				X
Overall Rating				
Risk				X
Benefit				X

Research and Development Potential: This is the technology found in low metal mine detectors. The technology for building rugged, stable, highly sensitive instruments is mature, but research is needed on understanding the response due to the environment, signal processing techniques to discriminate targets from metal fragments and background clutter and integrating metal detector systems with other sensors.

Canadian Experience: DRES has conducted research in detection of metal mines and UXO since 1977 and is considered a world leader in the field. They have developed detector prototypes and discrimination techniques for large metal objects, have integrated metal detector arrays into vehicle mounted multisensor mine detector systems, have done phenomenology studies on environmental effects and have conducted trials in theatre for CMAC and UNMAC. Canadian industry is a world leader in geophysical systems and one Canadian detector is widely used for UXO throughout the world.

Relevance to Humanitarian Demining: The low metal mine detector is the only type of sweeping detector used in humanitarian de-mining operations. These detectors can be made sufficiently sensitive to detect virtually all mines. However at those sensitivities, FAR is much too high. Signal processing and/or combination with other sensors is required to reduce FAR to acceptable levels.

Recommendation: R&D should be done on possible discrimination of different small metal components and background materials. This should be harmonized with work under the U.S. MURI program to avoid duplication of effort. R&D should be done to address integration issues in combining metal detectors and other sensors in hand held systems, particularly with regard to metal components and RFI.

Nuclear Techniques (Hand Held)

	Very Poor	Poor	Good	Very Good
R&D				
Time			X	
Human Resources/Cost			X	
Likelihood of Success		X	X	
DRDB R&D Capability				X
Cdn External R&D Capability				X
Implementation				
Capital Cost			X	
O&M Cost				X
Overall Rating				
Risk			X	
Benefit			X	

Research and Development Potential: Nuclear techniques have been exhaustively studied. Few reactions, including thermal and fast neutron analysis, are applicable to hand held use. Two possible exceptions are X-ray backscatter and neutron moderation. Both techniques have been tried in a nonimaging form and have failed badly. There is some hope that imaging would reduce the FAR to make them viable and University of Florida and Sandia labs are developing a full width vehicle mounted X-ray backscatter imaging detector. X-ray imaging may be limited by poor depth penetration in soil. Both techniques can potentially be made small enough to be hand held.

Canadian Experience: DREO has much experience in nuclear detection and DRES and DREO were heavily involved in the development of a vehicle mounted TNA land mine detector. DRES has conducted contracted R&D on X-ray backscatter imaging of mines. Certain Canadian industry and universities are world leaders in nuclear detection R&D.

Relevance to Humanitarian Demining: Nuclear detectors could be used to reduce the false alarm from metal detectors and GPR. They could be combined in a multisensor hand held detector. The two techniques proposed are not, however, confirming sensors, since they are based on rate change rather than radiation of a specific energy or type.

Recommendation: X-ray backscatter imaging R&D is being conducted by the U.S., but the proposed system is large and heavy, being intended as a full width vehicle mounted detector. R&D on hand held X-ray imaging and neutron moderation imaging should be explored.

Ground Probing Radar (Hand Held)

	Very Poor	Poor	Good	Very Good
R&D				
Time			X	
Human Resources/Cost		X		
Likelihood of Success			X	
DRDB R&D Capability			X	
Cdn External R&D Capability			X	
Implementation				
Capital Cost		X		
O&M Cost			X	
Overall Rating				
Risk			X	
Benefit			X	

Research and Development Potential: A large number of Ground Probing Radar (GPR) systems and companies exist, but most of the effort has been directed toward geophysics and UXO detection, which is not applicable to nonmetallic mine detection. A few hand held GPR systems have been developed in the U.S., specifically for the HSTAMIDS mine detection program. Due to limitations of physics, GPR will never be adequate as a stand alone detector. HSTAMIDS trials have shown that even combined with metal detection and IR imagers, Pd/FAR combinations to date have been inadequate for hand held mine detection.

Canadian Experience: DREO and DRES have substantial experience in radar in general and GPR in particular. GPR efforts have been on vehicle mounted mine detection and DRDB does not have any experience with hand held GPR systems. There are several companies in Canada that are experienced in radar and a few that are experienced in GPR. None have experience in GPR mine detection.

Relevance to Humanitarian Demining: GPR could be used as part of a multisensor hand held detector to reduce the existing high FAR of metal detectors.

Recommendation: R&D should be leveraged off the U.S. program as much as possible to avoid duplication of effort. General GPR development should not be done, rather, only aspects unique to hand held mine detection. If hand held GPR are available for loan or purchase, they should be tested to determine performance and limitations. If not available or if the testing suggests areas for improvement, R&D should be done to study the response of hand held GPR to varying environmental conditions, with an aim to developing methods to improve Pd and FAR. Hand held GPR should be investigated to identify and overcome compatibility issues related to multisensor integration, such as RFI and proximity of sensors.

Enhanced Infrared Imaging

	Very Poor	Poor	Good	Very Good
R&D				
Time			X	
Human Resources/Cost			X	
Likelihood of Success		X		
DRDB R&D Capability				X
Cdn External R&D Capability			X	
..				
Implementation				
Capital Cost		X		
O&M Cost		X		
Overall Rating			X	
Risk				
Benefit		X		

Research and Development Potential: Passive infrared imaging, both in the 3-5 and 8-14 micron wavebands, has been used for many years in a countermine role to detect buried and surface mines in airborne, vehicle mounted and hand held applications. Performance has varied from poor to excellent with the time of day and season, terrain and environmental conditions. In some cases performance can be predicted. Passive IR imaging performs poorly when all but the shortest of vegetative cover exists. Certain technologies can be used to enhance the performance, such as preconditioning the mine site with high power microwaves (HPM) or high power laser radiation, prespraying with water and by filtering. R&D on HPM/IR is being carried out by DREO, the U.S. (MURI program), Australia and New Zealand, with limited promise. HPM or laser enhancement has some potential to eliminate the zero contrast ``cross over'' periods found in passive IR imaging, to improve contrast of mines versus background and to improve effective spatial resolution of shallow buried objects. Filtering has the potential to reduce day time clutter.

Canadian Experience: DRDB has considerable experience in both the phenomenological and image processing aspects of passive infrared imaging of land mines at DRES and DREV. DREO has had a small program in HPM/IR for the past two years. There is a good general infrared technology background in Canadian industry and companies exist that manufacture thermal IR imagers. There is little experience, however, related to mine detection.

Relevance to Humanitarian Demining: IR imaging, regardless of enhancement, is impeded by all but the shortest vegetative cover. Such cover is pandemic in humanitarian de-mining. It would still be of some use in certain limited scenarios, such as roads, tracks and some cleared land. For HPM and laser enhancement, it is necessary to know the rough position of the suspected mine. HPM or high power laser enhancement is only suitable for small stand offs, due to power requirements. The logistics burden is much greater than the benefit gained or than what deminers would reasonably accept.

Recommendation: The small potential performance gain over passive IR imaging vis a vis the cost and logistics burden of the microwave of laser sources required for HPM/IR or laser/IR precludes them from a humanitarian de-mining role. A limited role may exist for HPM/IR in countermine applications if HPM is already being employed as a neutralization technique. Thus a small effort

in HPM/IR funded through the countermine program may be appropriate. The vegetation problem makes IR imaging generally unattractive for de-mining. Prespraying and enhanced filtering techniques should be explored, but these are low cost and can be funded through the countermine program.

Combined Sensors and Data Fusion

	Very Poor	Poor	Good	Very Good
R&D				
Time			X	
Human Resources/Cost			X	
Likelihood of Success			X	
DRDB R&D Capability				X
Cdn External R&D Capability				X
--				
Implementation				
Capital Cost			X	
O&M Cost				X
Overall Rating				
Risk			X	
Benefit			X	X

Research and Development Potential: Most investigators agree that multiple sensors are necessary to achieve the required performance level for land mine detection. In order to optimize the Pd and FAR, and to present information to the operator in a useful manner, data fusion is necessary. A considerable body of work exists in the area of data fusion, but it is often generic, theoretical or of a classical nature, which is not suited to the problem.

Canadian Experience: DRDB has considerable experience and expertise developing data fusion software for the ILDP program, and this software is among the most advanced of competing software for multisensor vehicle mounted mine detectors. There are also some Canadian companies with substantial experience in airborne and vehicle mounted multisensor fusion. There is no expertise specifically directed toward hand held detection.

Relevance to Humanitarian Demining: In order to improve the performance of the currently used hand held metal detector, it will be necessary to combine it with additional complementary sensors. Data fusion will be essential to make these work together seamlessly.

Recommendation: Selection and development of additional sensors is covered elsewhere. A program to investigate data fusion for hand held multisensor land mine detection should be initiated. Generic R&D should be avoided in favour of supporting integration of specific sensor combinations.

Optical Trip Wire Detection

	Very Poor	Poor	Good	Very Good
R&D				
Time			X	
Human Resources/Cost			X	
Likelihood of Success			X	
DRDB R&D Capability			X	
Cdn External R&D Capability				X
Implementation				
Capital Cost			X	
O&M Cost			X	
Overall Rating				
Risk			X	
Benefit			X	

Research and Development Potential: Modern advances in optical technology may provide the ability to detect the thin trip wires associated with many land mines. Although they are almost invisible against background, appropriate selection of wavebands and algorithms may render them visible.

Canadian Experience: A pilot study on optical wire detection was carried out, sponsored by the Canadian Space Agency STEAR program and DRES. The results were sufficiently promising to warrant future work.

Relevance to Humanitarian Demining: If detection is robust against a variety of backgrounds, a potential detector could be made in a compact form for hand held use. Attached to a metal detector, it would look immediately in front of the detector and/or to the side.

Recommendation: Effort should be directed toward establishing a proof of concept prototype detector.

Teleoperated "Hand Held" Detection

	Very Poor	Poor	Good	Very Good
R&D				
Time			X	
Human Resources/Cost			X	
Likelihood of Success			X	
DRDB R&D Capability			X	
Cdn External R&D Capability			X	
Implementation				
Capital Cost			X	
O&M Cost			X	
Overall Rating				
Risk			X	
Benefit			X	

Canadian Experience Research and Development Potential: Teleoperation and robotics have matured to the point where it is reasonable to consider small teleoperated platforms that could deliver mine detection sensors to their required destinations and operate them there. Most such sensors require a scanning motion and, for ideal performance, must follow the profile of the ground. Development is not trivial, since most scanning mechanisms have substantial amounts of metal and electrical motors which interfere with sensitive electromagnetic sensors.

Canadian Experience: There is considerable expertise at DRES in teleoperation of vehicles, including those for mine detection. DCIEM has expertise in teleoperation and robotics. DRES has a small contracted project to investigate the use of a scanning arm with the capability of constant standoff from the ground. The arm would be mounted on a small, mobile, teleoperated platform and could sweep a ``hand-held'' metal detector or GPR in the same manner that a person does.

Relevance to Humanitarian Demining: Teleoperation of scanning sensors would remove the operator from danger and relieve the tedium of the search.

Recommendation: Platforms should be considered under ``Enabling Technologies'' to harmonize with the rest of that program. Any effort should address only the aspects of platforms necessary for the de-mining role, since development for general IED neutralization is driven by other sources. Development of a ground following scanning arm should be continued.

Nuclear Quadrupole Resonance

	Very Poor	Poor	Good	Very Good
R&D				
Time			X	
Human Resources/Cost			X	
Likelihood of Success			X	
DRDB R&D Capability		X	X	
Cdn External R&D Capability		X	X	
Implementation				
Capital Cost		X		
O&M Cost			X	
Overall Rating				
Risk			X	
Benefit			X	

Research and Development Potential: NQR has been researched for a long time, but its application to mine detection has been slow due to well known technical problems. Quantum Magnetics (QM) of San Diego claims to have solved the majority of these problems. Published data and data presented at meetings between DRES and QM suggest that NQR may be a viable confirmation sensor which could be fielded in the near future. Most of this work is being financed by multimillion dollar contracts from DARPA and the U.S. Marines with the goal of developing a mine detector which operates at the same sweeping speed as a metal detector. TNT cannot yet be detected reliably, but QM says that the capability will be in place for the Spring 1999 DRES trials.

Canadian Experience: DRES has monitored research on NQR mine detection since the late 1970's, but no in-house research has been done due to the high costs. DRES has a contract with Quantum Magnetics to carry out trials against live mines, aimed at hand held and/or vehicle mounted confirmatory detection.

Relevance to Humanitarian Demining: Has potential to be a noncontact detector. Measurements will likely be slow, but suitable for confirmatory detection. Could be hand held, but likely on an umbilical at first. NQR cannot detect explosive in metal cased mines, but it might be combined with a metal detector or even operate as a metal detector itself. Initially it will be very expensive. Electromagnetic radio frequency interference is a concern.

Recommendation: Effort should be directed toward funding any specialized aspects of NQR that are necessary to ensure its use as a confirmatory detector for AP mines. The costs for this incremental work should be relatively low, since it is leveraged against the U.S. development program for a full speed sweeping detector.

Electrical Impedance Tomography

	Very Poor	Poor	Good	Very Good
R&D				
Time			X	
Human Resources/Cost			X	
Likelihood of Success			X	
DRDB R&D Capability			X	
Cdn External R&D Capability				X
..				
Implementation				
Capital Cost			X	
O&M Cost			X	
Overall Rating				
Risk			X	
Benefit			X	

Research and Development Potential: This technology can theoretically image subsurface electrical conductivity, based on surface impedance measurements. While it is in the early stage of development, it is one of the few potential techniques for producing images of metal or non metal objects. Significant R&D still needed to establish feasibility.

Canadian Experience: DRES contracted research on EIT algorithm development for the more general problem of unexploded ordnance detection for several years during the 1980's. Research was stopped in 1990 due to poor results, chiefly caused by the difficult measurement geometry. More measurement-oriented work was restarted in 1998 aimed at the less difficult geometry associated with shallow buried mines. Initial work looks very promising.

Relevance to Humanitarian Demining: Practical problem caused by the need to contact the ground near mine. Measurements may be slow. Could be suitable for detection of all mine types in a confirmatory role, as a noncontact replacement for the prodder. Could be made almost as simple to operate as a metal detector.

Recommendation: Effort should be directed toward establishing proof of concept for shallow mine detection.

Trace Explosive Detection (TED)

	Very Poor	Poor	Good	Very Good
R&D				
Time		X	X	
Human Resources/Cost		X	X	
Likelihood of Success		X	X	
DRDB R&D Capability			X	
Cdn External R&D Capability				X
Implementation				
Capital Cost		X		
O&M Cost		X		
Overall Rating				
Risk		X	X	
Benefit		X	X	

Research and Development Potential: This area includes chemical and biochemical detection and dogs. DARPA is expending an enormous effort on TED. DREV/DRES studies have shown that vapour densities above a mine are too low to be detected, but that explosive particle concentrations in soil above a mine are detectable using sensitive GC/IMS detectors and biochemical sensors hold promise for even more sensitivity. Localization of individual mines is difficult due to cross contamination. TED may have the potential for identification of wide areas that are mined. Solid state detectors in a mine prodder may be able to detect high particulate concentrations on the mine case. Information about performance of dogs is anecdotal and contradictory, although recent studies may have clarified the confusion.

Canadian Experience: DREV had a significant effort in TED directed at improvised explosive devices, from the mid 1970's to the early 1980's. DREV started mine detection studies in 1994 in support of ILDP. They have been ongoing at a low level since then, involving analysis of detector trials and some detector development.

Relevance to Humanitarian Demining: If sufficiently sensitive, TED could be used for Level II survey. If solid state sensors of sufficient sensitivity are available, they could augment or replace the sensor in the Smart Probe as a confirmation tool.

Recommendation: Numerous questions must be answered to determine feasibility. Much debate exists over what is the concentration of explosives on mine case exteriors and in soil above a mine. If favourably answered, development of fast soil sampling probes, wide area samplers and miniature prodder sensors can be started. The discrepancies in reported Pd, FAR, overall performance and which variables affect these ranges, must be resolved for dogs. A number of available studies and reviews, some quite recent, must first be assessed prior to considering any future work.

Augmented Prodders

	Very Poor	Poor	Good	Very Good
R&D				
Time				X
Human Resources/Cost			X	
Likelihood of Success			X	
DRDB R&D Capability				X
Cdn External R&D Capability			X	
--				
Implementation				
Capital Cost			X	
O&M Cost				X
Overall Rating				
Risk			X	
Benefit			X	

Research and Development Potential: Technologies which augment the mechanical prodder may make it easier to use or improve Pd and FAR. There currently exists a ``Smart Probe'', which is based on analysing acoustic signals returned by reflections off materials contacting the prodder tip. It was developed for military countermine use, but with modifications could be suitable for humanitarian de-mining. Alternative sensor technologies might be put in a prodder tip to enhance mine detection. These could include solid state trace explosive sensors, lenses coupled by optical fibres to a VNIR spectrometer or a broadband visible imager (eyepiece for visual inspection). Technologies which aid penetrating very hard ground would be useful.

Canadian Experience: DRES has developed the Smart Probe which is now at the EDM stage. Two companies, HF Technologies and DEW, have substantial experience in the development of the Smart Probe.

Relevance to Humanitarian Demining: The prodder is the only confirmation detector now in practical use. Augmenting it could improve Pd and FAR.

Recommendation: Some development effort should be directed to improving and modifying the EDM Smart Probe for de-mining use. This could include relaxing MIL-specs to reduce costs, developing a standard test methodology, and improving the acoustic detection algorithms. The basic science of the probe should be looked at to quantify and understand what factors affect performance. The adoption of automation and remote control should be considered under ``Enabling Technologies'', but only after the performance is well understood. Feasibility studies should be done to investigate alternative sensors. Methods and tools for probing very hard ground should be investigated.

Optical Spectroscopy

	Very Poor	Poor	Good	Very Good
R&D				
Time			X	
Human Resources/Cost			X	
Likelihood of Success			X	
DRDB R&D Capability				X
Cdn External R&D Capability				X
Implementation				
Capital Cost			X	
O&M Cost			X	
Overall Rating				
Risk			X	
Benefit			X	

Research and Development Potential: VNIR hyperspectral imaging (HSI) has been shown to reliably detect surface-laid mines and to detect buried mines but with poorer Pd and FAR. VNIR/UV techniques are of limited use to de-mining, since they cannot detect long buried mines. SWIR and TIR HSI may be able to reliably detection surface and buried mines with simplified algorithms. Early stage DARPA-funded research is trying to develop genetically altered ``bio-reporter'' bacteria which can be sprayed over a large area and are selectively attracted to explosives in mines. The bacteria, which either fluoresce on excitation or bioluminesce, are then detected using an airborne UV imager. The ability to selectively localize mines, background clutter problems and logistics are a concern. A UV HSI may offer some advantages for this. The use of optical fibres to couple a lens in the Smart Probe tip to a VNIR spectrometer, or to a simple broadband imager (eyepiece lens for visual inspection) could reduce FAR by identification of the casings of contacted buried mines.

Canadian Experience: DRES and Itres Research have been conducting R&D on VNIR HSI detection of surface laid mines since 1989. DRES has done buried mine VNIR HSI detection R&D since 1995. DREV funded development of an Itres-made intensified HS imager for search and rescue. SWIR expertise rests with CCRS from a now defunct program. Itres is a world leader in airborne VNIR HSI, with their *CASI* imager. Little experience in TIR HSI exists in Canada. A DIR project with Itres was started in Oct.1998 to develop a SWIR HS imager for mine detection. DREV, in conjunction with NRC, has considerable experience in development of biotechnology for biodegradation of explosives in soil. This would be directly applicable to bio-reporter studies.

Relevance to Humanitarian Demining: Airborne HSI could greatly assist Level I surveys to identify suspected mined areas. A spectrometer augmented prodder could reduce FAR in a confirmation role.

Recommendation: A program to investigate the feasibility of detecting mines using SWIR/TIR HSI for Level I survey should be initiated. This can leverage off the DIR project to develop the SWIR HS imager, and thus concentrate on the phenomenology. A feasibility study should be conducted to see if it is useful and practical to couple a VNIR spectrometer or broadband imager to the Smart Probe. Research on bio-reporters could be both interesting and high

payoff. However, the risk and costs are high. The DARPA program should first be monitored to see if information is readily available and if there are niche areas that need exploration or areas for collaboration. The use of a UV HS imager may be a niche area.

Acoustic/Seismic Detection

	Very Poor	Poor	Good	Very Good
R&D				
Time		X		
Human Resources/Cost		X		
Likelihood of Success	X			
DRDB R&D Capability			X	
Cdn External R&D Capability			X	
Implementation				
Capital Cost		X		
O&M Cost			X	
Overall Rating				
Risk	X			
Benefit		X		

Research and Development Potential: This discussion excludes techniques where the detector contacts the mine, since this is covered under ''Augmented Prodders''. There has been and continues to be substantial research on acoustic/seismic detection of buried mines, mainly in the U.S. Low metal content and nonmetallic mines have been detected in restricted conditions but false alarm rate due to soil inhomogeneity and natural inclusions is prohibitively high. Present research, including resonance techniques, has not altered these results. Mine discrimination using crude imaging was attempted with poor results.

Canadian Experience: DRES sponsored a small study on the feasibility of detecting mines buried in sand. The results were discouraging. DREA has extensive experience in acoustics. Several Canadian companies have experience in acoustics/seismic technology.

Relevance to Humanitarian Demining: Imaging is required to handle the false alarm problem and this leads to equipment which is too complex for humanitarian de-mining and slow speeds. The speed relegates its role in confirmation only, where it offers no real advantage over more feasible methods. System would likely have to be vehicle mounted. Some versions must contact the ground.

Recommendation: Since the U.S. continues to have a significant R&D effort in this area, Canada's most cost effective approach is to monitor the research for now. Proposals should address past failures and clearly show how these will be circumvented.

MINE NEUTRALIZATION TECHNOLOGIES

Adaptation of Military Mechanical Breaching Equipment

	Very Poor	Poor	Good	Very Good
R&D				
Time		X		
Human Resources / Cost	X			
Likelihood of Success			X	
DRDB R&D Capability			X	
Cdn External R&D Capability		X		
Implementation				
Capital Cost	X			
O&M Cost		X		
Overall Rating				
Risk			X	
Benefit			X	

Research and Development Potential: This is old technology that is focussed on breaching track and full-width assault lanes through minefields for armoured fighting vehicles. There is little national military focus on improving this technology.

Canadian Experience: The Canadian Army has used these machines for decades. In ideal conditions, the heavy equipment clears most mines in front of the vehicle, but not to the UN humanitarian demining standard of 99.6%. The machines are sensitive to terrain and obstacles.

Relevance to Humanitarian Demining: Most military mechanical breaching equipment has limited utility for humanitarian demining. The machines are very heavy and can be difficult to move to the work site. Furthermore, the logistics support requirements for these systems are often high and costly. It is beyond the resources available to many humanitarian demining organisations.

Recommendation: There may be scope to adapt some of the working principles from these systems to small scale machinery, but this is more of less of an engineering nature. It is not recommended that CCMAT embark on the development of such equipment.

Explosive Breaching Equipment (Explosive hoses, etc.)

	Very Poor	Poor	Good	Very Good
R&D				
Time				X
Human Resources / Cost		X		
Likelihood of Success		X		
DRDB R&D Capability				X
Cdn External R&D Capability			X	
Implementation				
Capital Cost		X		
O&M Cost		X		
Overall Rating				
Risk			X	
Benefit	X			

Research and Development Potential: Current, in-service explosive breaching equipment consists mainly of hoses filled with solid high explosive, which are known to be only partly effective. A number of replacement systems, using an array of shaped charges or explosive hoses, are under development. This technology has reached some level of maturity, but requires further development before implementation.

Canadian Experience: DRES and its industrial partners have extensive experience in the development of explosive breaching technology. This includes a thorough understanding of explosive types, explosive geometry, shock interaction with the soil and mines, etc.

Relevance to Humanitarian Demining: This technology is a gross overmatch for the humanitarian demining role. It was designed for combat situations where speed of advance is paramount. The large explosive content, of the order of several tonnes, also makes these systems too costly for this role.

Recommendation: It is not recommended that CCMAT support research or T&E for this category of systems.

Vegetation Clearance Equipment (Mulchers, Stump Grinders, etc.)

	Very Poor	Poor	Good	Very Good
R&D				
Time				X
Human Resources / Cost			X	
Likelihood of Success			X	
DRDB R&D Capability		X		
Cdn External R&D Capability				X
Implementation				
Capital Cost		X		
O&M Cost			X	
Overall Rating				
Risk			X	
Benefit				X

Research and Development Potential: This technology has been developed extensively for civilian applications in forestry and agriculture. There is a need to research how to best adapt it for the humanitarian demining role. This may include means to minimise disturbances of the ground, despite undulations or local slopes, and to remove the mulch from the areas cleared. There may also be a need to harden the crew compartment and working end of the equipment to minimise damages from accidental explosions.

Canadian Experience: Given its geography and vast natural resources, Canada has a very strong industrial technology base from which to draw from. CCMAT has a very good understanding of the mission and the threat, and could work with industry to adapt the equipment for the mission proposed.

Relevance to Humanitarian Demining: In some theatres, deminers spend the major portion of their time removing vegetation. The successful introduction of appropriate mechanical assistance for this role would have a significant impact on the rate of demining. Depending on the size of equipment and armour system used, it could also offer much improved protection from anti-personnel fragmentation mine effects. These benefits would be obtained in spite of the usually large acquisition cost of the prime mover for these systems.

Recommendation: This is one area where Canadian industry could carve a niche market because this type of systems is only beginning to be proposed to the humanitarian demining community. CCMAT should work with Canadian industry by providing advice on the mission and T&E services wherever appropriate.

Large Scale Area Clearance Machinery (Flails, Soil mills, Sifts, etc.)

	Very Poor	Poor	Good	Very Good
R&D				
Time			X	
Human Resources / Cost	X			
Likelihood of Success			X	
DRDB R&D Capability			X	
Cdn External R&D Capability		X		
Implementation				
Capital Cost	X			
O&M Cost		X		
Overall Rating				
Risk			X	
Benefit			X	

Research and Development Potential: These machines are mostly adaptations from commercial or military equipment. The power train and prime mover aspects of these systems are well developed by Industry. In most cases, these systems have an on-board human operator. R&D would be required to tele-operate these systems and provide electronic navigation. Improvements could also be made to their end effector mechanisms.

Canadian Experience: The Canadian Army has used the large JFSU flail in Bosnia with good results. There exists a solid knowledge base in the agricultural and construction industries for the development of several aspects of other systems. CCMAT has a very good understanding of the mission and the threat, and could work with industry to adapt the equipment for the mission proposed.

Relevance to Humanitarian Demining: Several large flails, soil mills and sifts have been developed and tested for use in humanitarian demining. Although some test results indicate that there exists some limitations, these machines have demonstrated that they can be used successfully for this mission.

Recommendation: Although Canadian industry could develop this class of systems, it would face fierce competition from foreign manufacturers that already have products in the field. Furthermore, R&D with these systems is costly and is covered extensively by other countries. CCMAT should simply monitor any new developments of this technology and be prepared to offer advice. T&E of this equipment is not recommended.

Air, Water Jet Systems

	Very Poor	Poor	Good	Very Good
R&D				
Time				X
Human Resources / Cost			X	
Likelihood of Success			X	
DRDB R&D Capability			X	
Cdn External R&D Capability			X	
Implementation				
Capital Cost			X	
O&M Cost				X
Overall Rating				
Risk			X	
Benefit		X		

Research and Development Potential: Air and water jet systems have been used with success to uncover buried objects and to neutralize a variety of munitions. There is little R&D to conduct in the development of the systems themselves, except maybe to reduce water consumption and in further evaluation of the interaction of the jet with buried mines. Tests of the Air Spade™ by the US demonstrate that an air jet can be effective to uncover mines, depending on soil type and the density of the root structure surrounding the buried object.

Canadian Experience: The National Research Council of Canada conducted some studies of the effectiveness of water jets to uncover buried objets. DRES initiated the development of a similar system to study the potential of this technology for countermine applications, but the system was never put into service due to lack of funding and priority.

Relevance to Humanitarian Demining: This type of system has its place in humanitarian demining, particularly during the investigation of an object that could be booby-trapped. An air jet system is already integrated on a remote controlled vehicle, but the system has met only with limited success to date.

Recommendation: In light of its limited budget, CCMAT should not pursue the development of this kind of system. There are already units in existence and CCMAT should limit its activities to monitoring the evolution of the technology.

Binary Explosives

	Very Poor	Poor	Good	Very Good
R&D				
Time				X
Human Resources / Cost				X
Likelihood of Success				X
DRDB R&D Capability				X
Cdn External R&D Capability				X
Implementation				
Capital Cost				X
O&M Cost				X
Overall Rating				
Risk			X	
Benefit			X	

Research and Development Potential: Various research centres and companies around the world have developed binary explosive systems over the past few years. Many of these explosives have a Velocity of Detonation that is substantially less than for military explosive, but there may exist techniques to enhance their performance through packaging and wave shaping. There is a need for T&E to determine which candidates can perform the demolition task.

Canadian Experience: Canadian Industry and DRES have excellent expertise in this type of technology. DRES sponsored the development of a number of binary explosives and novel explosive formats in the past and has considerable in-house expertise in tailoring the use of these explosives to enhance their performance.

Relevance to Humanitarian Demining: A reliable binary explosive would be very useful in humanitarian demining. It could replace many less reliable explosives that are known to cause problems in the field.

Recommendation: CCMAT should support Canadian industrial developments of binary explosives by providing expert advice in their use to defeat munitions. T&E support can also be provided on the DRES Experimental Proving Grounds.

Shaped Charges

	Very Poor	Poor	Good	Very Good
R&D				
Time			X	
Human Resources / Cost			X	
Likelihood of Success			X	
DRDB R&D Capability				X
Cdn External R&D Capability			X	
Implementation				
Capital Cost			X	
O&M Cost			X	
Overall Rating				
Risk			X	
Benefit		X		

Research and Development Potential: There have been a number of studies about the usefulness of shaped charge technology to destroy unexploded ordnance. Some studies were also concerned with the defeat of buried mines for military breaching applications using high precision shaped charges. Further R&D is required to quantify the relationship between the amount of soil overburden and the initiation threshold for different explosives. Variations in the liner material could also be studied.

Canadian Experience: DRES has extensive experience in the design and applications of shaped charges. An industrial support base also exists to manufacture the product.

Relevance to Humanitarian Demining: This technology represents one of many tools in the toolbox approach to humanitarian demining. Situations may arise where a shaped charge is the most effective means to destroy some munitions.

Recommendation: R&D for this technology is already being paid under existing military programs. In light of its limited budget, CCMAT should not fund the development of this technology and limit its activities to monitoring the progress of the technology.

Exothermic Materials (Thermite, etc.)

	Very Poor	Poor	Good	Very Good
R&D				
Time				X
Human Resources / Cost				X
Likelihood of Success		X		
DRDB R&D Capability			X	
Cdn External R&D Capability				X
--				
Implementation				
Capital Cost				X
O&M Cost				X
Overall Rating				
Risk		X		
Benefit		X		

Research and Development Potential: This technology has the advantage that it is not an explosive, which greatly eases the transport and storage requirements for these materials. Tests to gauge how it can be used to destroy mines showed mixed success. Systems that produce a hot jet show superior performance over those that rely exclusively on heat conduction. Means to contain the hot slag need to be found when detonation of the mine occurs. Further T&E is required to define the mode of attack for individual mines.

Canadian Experience: Several Canadian companies proposed systems to neutralize mines using this technology. DRES tested these products against fused and armed mines and found that they often require specific placement to defeat their target. Transition to detonation can occur depending on the internal configuration of the mine and the mode of attack used.

Relevance to Humanitarian Demining: This technology has limited application to humanitarian demining. In theatres where transport and storage of an explosive is highly restricted, it represents a reasonable alternative provided measures are taken to prevent the spread of fires in case of an unwanted detonation.

Recommendation: In light of its limited budget and the limited chances of success for application of this technology to humanitarian demining, CCMAT should not fund the development of this technology and limit its activities to monitoring the progress of the technology.

Fundamentals of Tool/Soil/Mine Interaction

	Very Poor	Poor	Good	Very Good
R&D				
Time			X	
Human Resources / Cost			X	
Likelihood of Success			X	
DRDB R&D Capability		X		
Cdn External R&D Capability				X
Implementation				
Capital Cost		X		
O&M Cost			X	
Overall Rating				
Risk			X	
Benefit				X

Research and Development Potential: The science of terramechanics has seen many developments in the past decades to improve the mobility of vehicles and the effectiveness of agricultural or construction machinery. New R&D is required to link the principles from this science with the mine neutralization application, principally in quantifying the effects of various mechanical actions on the mine activation mechanisms as a function of soil conditions.

Canadian Experience: DRDB used to be very proficient in this domain, but this area or research is winding down as a result of cutbacks. However, a substantial pool of expertise remains within Canadian universities, which could be consulted in this matter.

Relevance to Humanitarian Demining: A detailed quantification of the mechanisms of the tool/soil/mine interaction offers much potential for the improvement of mechanical assistance systems currently proposed. These improvements could be in regard to how the equipment is being used or in the design of the equipment itself.

Recommendation: It is recommended that CCMAT sponsor some Canadian universities to define and quantify the tool/soil/mine interaction. DRDB should also get involved in a limited R&D program in coordination with the university work.

Mechanical Mine Surrogates

	Very Poor	Poor	Good	Very Good
R&D				
Time				X
Human Resources / Cost			X	
Likelihood of Success			X	
DRDB R&D Capability				X
Cdn External R&D Capability			X	
Implementation				
Capital Cost		X		
O&M Cost			X	
Overall Rating				
Risk			X	
Benefit				X

Research and Development Potential: There are several mechanical actuation mechanisms incorporated in mines. The challenge is to reproduce the most widely used economically while providing features that will allow comprehensive T&E to be carried out. R&D is required to develop suitable equipment and test techniques.

Canadian Experience: As a consequence of its military countermine research over the past two decades, DRES is the recognised Canadian centre of expertise in regard to the functioning of landmines. They are best positioned to undertake this development with appropriate support from Canadian Industry.

Relevance to Humanitarian Demining: The importance of using landmines or realistic surrogates is paramount to assessing the performance of mechanical assistance equipment. Real landmines are used either to assess the survivability of the equipment to accidental detonation or the effectiveness of the tool. However, obtaining genuine landmines is increasingly difficult because of the ban treaty. Furthermore, they pose a significant hazard due to their explosive content. Development of a high fidelity mechanical surrogate is therefore a high priority that could become standard test equipment for the proposed ITEP.

Recommendation: This development should be high on CCMAT's priority list. It requires substantial funding that is beyond the interest of Industry due to its limited market, but it is a necessary step towards establishing credible T&E procedures for mechanical assistance equipment. CCMAT should sponsor this development.

PROTECTION TECHNOLOGIES

Performance of Existing Personal Protective Equipment

	Very Poor	Poor	Good	Very Good
R&D				
Time				X
Human Resources / Cost			X	
Likelihood of Success				X
DRDB R&D Capability				X
Cdn External R&D Capability				X
Implementation				
Capital Cost		X		
O&M Cost			X	
Overall Rating				
Risk				X
Benefit				X

Research and Development Potential: This is primarily a T&E exercise. However, there is a need for related R&D to define appropriate test standards and, in some cases, to develop the equipment necessary to support this work. This work includes both the protection of lower limbs by appropriate footwear, and demining ensembles to protect the upper body during neutralization tasks.

Canadian Experience: DRDB and selected Canadian companies have extensive experience in carrying out R&D for protective equipment. They are very well placed to do this work.

Relevance to Humanitarian Demining: There is a pressing need to test the performance of available personnel protective equipment and to disseminate the information to the field. This will have a direct impact on the safety of demining and recommendations will likely flow to the field as to which practices are safe and which are definitely not.

Recommendation: CCMAT should be involved directly in this type of T&E activities because of the substantial impact that it could have in the field.

Vehicle Protection

	Very Poor	Poor	Good	Very Good
R&D				
Time			X	
Human Resources / Cost		X		
Likelihood of Success			X	
DRDB R&D Capability				X
Cdn External R&D Capability			X	
Implementation				
Capital Cost	X			
O&M Cost		X		
Overall Rating				
Risk			X	
Benefit		X		

Research and Development Potential: Vehicle protection is an active field of military research with the current emphasis being placed on the characterisation of the effects of soil, standoff and explosive type. There is also continuous research in materials and construction techniques for vehicles.

Canadian Experience: DRDB has extensive experience with this kind of technology and in the design of protection systems for vehicles. There also exists a good industrial base for the production of protection materials and systems integration.

Relevance to Humanitarian Demining: Much of the technology developed under the military programs could be applied to the protection of mechanical assistance equipment. There is minimal need to protect vehicles used to transport equipment and personnel from site to site.

Recommendation: Given its limited financial resources and that vehicle protection can be costly, it is not recommended that CCMAT gets involved in this type of R&D activity. CCMAT should limit its activities to the provision of expert advice where and when required.

Likelihood of Injury versus Prodding Position

	Very Poor	Poor	Good	Very Good
R&D				
Time				X
Human Resources / Cost			X	
Likelihood of Success			X	
DRDB R&D Capability				X
Cdn External R&D Capability				X
Implementation				
Capital Cost		X		
O&M Cost			X	
Overall Rating				
Risk			X	
Benefit				X

Research and Development Potential: This activity represents only one component of a larger R&D program to enhance the protection of deminers. It must be linked with R&D to define appropriate test standards and to develop equipment with the anthropomorphic characteristics necessary to support this work.

Canadian Experience: The Canadian Forces and DRES have expertise in prodding procedures for military roles. Furthermore, expertise is also developing within Canadian Industry as some companies are getting very involved with humanitarian demining.

Relevance to Humanitarian Demining: Demining organisations have adopted various positions other than the prone position. There is very little data as to how different positions relate to the probability of injury that a deminer could suffer. Quantifying the implications of various prodding positions could lead to improvements in demining doctrine.

Recommendation: It is recommended that CCMAT sponsor a study to determine the likelihood of injury to deminer as a function of prodding position. This work could also form a contribution to ITEP through the development of test procedures and test equipment.

Human Factors

	Very Poor	Poor	Good	Very Good
R&D				
Time			X	
Human Resources / Cost			X	
Likelihood of Success			X	
DRDB R&D Capability				X
Cdn External R&D Capability				X
Implementation				
Capital Cost			X	
O&M Cost			X	
Overall Rating				
Risk				X
Benefit			X	

Research and Development Potential: There exists test and analysis methods to conduct human factor studies. This could benefit Canadian companies that are developing humanitarian demining equipment. This work therefore consists mostly of T&E to support R&D efforts.

Canadian Experience: DCIEM has extensive experience in these kinds of activities. There also exists a consultant base within Canadian Industry that can support this type of work.

Relevance to Humanitarian Demining: Many developments for demining equipment are conducted in consultation with organisations actively involved in demining. The personnel protection needs are therefore sufficiently well understood to proceed with the development of equipment. Human factor studies may however be of benefit at a later data to help define specific areas for improvements to the equipment.

Recommendation: Given its budget limitations, it is recommended that the CCMAT focus be on the development of the equipment first. If sufficient funding becomes available, human factors studies could also be sponsored.

T&E Standards

	Very Poor	Poor	Good	Very Good
R&D				
Time			X	
Human Resources / Cost			X	
Likelihood of Success			X	
DRDB R&D Capability			X	
Cdn External R&D Capability			X	
Implementation				
Capital Cost			X	
O&M Cost		X		
Overall Rating				
Risk		X		
Benefit				X

Research and Development Potential: The development of standards requires a high degree of international participation if it is to be truly useful. It must also be based on a sufficiently strong data base so that the processes at play are well captured. R&D is required to identify and quantify these processes. There will also be different processes at play depending on the mode of injury, e.g., for the lower versus the upper body.

Canadian Experience: DRDB and selected Canadian companies participated in the definition of several standards over its existence, albeit its principle role has been to develop the knowledge base required to carry out this work.

Relevance to Humanitarian Demining: There is a need to define T&E standards to rate the performance of personnel protective equipment. This will provide a reference framework to help demining organisations in their selection of equipment for their environment and threat. ITEP is expected to be a strong participant in this activity.

Recommendation: The definition of standard is a difficult issue that takes much time to complete. Given the timeframe that governs CCMAT's activities, it is recommended that it restrict its activities to the definition of T&E protocols to support its activities. These protocols will be valuable contributions to ITEP in themselves.

Blast Manikin

	Very Poor	Poor	Good	Very Good
R&D				
Time			X	
Human Resources / Cost		X		
Likelihood of Success			X	
DRDB R&D Capability			X	
Cdn External R&D Capability				X
Implementation				
Capital Cost		X		
O&M Cost			X	
Overall Rating				
Risk			X	
Benefit				X

Research and Development Potential: The current thrust in regard to testing personnel protective ensembles is to use anthropomorphic manikins from the automotive industry. Much R&D is required to quantify the response of these devices to blast loads and relate the output to actual injury mechanisms.

Canadian Experience: Anthropomorphic manikins have been used for blast injury work sporadically within DRDB and Canadian Industry during the past two decades. In most instances, these devices were used in a differential mode that required only a minimal link to human injury. On the other hand, there exists a very good industrial base for the use of anthropomorphic manikins for the automotive crash application.

Relevance to Humanitarian Demining: There is a need to develop blast manikins suitable for the evaluation of personnel protective equipment. The importance of this development is closely related to that of providing expert advice on the performance and suitability of the protective equipment.

Recommendation: The full-scale development of a blast manikin is an expensive venture that is beyond the resources available to CCMAT. However, if CCMAT can find international partners to carry out this work, it is recommended that it proceed. The results from this work should have a substantial impact on the credibility of related activities.

Ballistic and Shock Absorbing Materials

	Very Poor	Poor	Good	Very Good
R&D				
Time		X		
Human Resources / Cost			X	
Likelihood of Success			X	
DRDB R&D Capability				X
Cdn External R&D Capability				X
Implementation				
Capital Cost			X	
O&M Cost			X	
Overall Rating				
Risk			X	
Benefit			X	

Research and Development Potential: This is a field where there is much on going research, particularly with respect to improved composite materials that are lighter and stronger. Shock "absorption" materials are also under investigation.

Canadian Experience: DREV gained extensive experience with this kind of research as part of its military programs. In the process, they participated in the development of a strong Canadian Industry that can produce a variety of vehicle and body armour materials.

Relevance to Humanitarian Demining: There is a need for this kind of research as it flows into the design of personnel protective equipment. More conventional protective materials, such as steel and aluminium can be used for the protection of mechanical equipment.

Recommendation: Given its budget limitations, CCMAT should give lower priority to this activity in comparison with other activities that have been proposed. The current state of knowledge within Industry should satisfy the requirements for the development and testing of the personnel protective equipment that has been proposed.

Numerical Modelling

	Very Poor	Poor	Good	Very Good
R&D				
Time			X	
Human Resources / Cost			X	
Likelihood of Success			X	
DRDB R&D Capability				X
Cdn External R&D Capability				X
Implementation				
Capital Cost			X	
O&M Cost			X	
Overall Rating				
Risk			X	
Benefit			X	

Research and Development Potential: There are different levels of involvement for numerical technology, depending whether one is trying to develop a predictive capability or analysis tools to help in the interpretation of experimental data. This is a very active field of research with efforts going into the development of improved physical models with fluid-structure interaction and more realistic materials models.

Canadian Experience: There exists a very good network of numerical specialists within DRDB, Canadian Industry and universities that cover all research aspects of this technology. In particular, DRES and DREV have sponsored the development of codes that can be applied directly to the interaction of mine blast with structure and personnel.

Relevance to Humanitarian Demining: This technology does not have a direct influence on what happens in the field. Rather, it is a tool used by the scientific community to deliver on its research. As such, it plays an instrumental role during the analysis and interpretation of experimental data.

Recommendation: CCMAT should support some level of numerical modelling where it can help in the interpretation of experimental results. Two areas that are good candidates are in a study of prodding positions and in the interpretation of physical damages to lower limbs.

Enhanced Foot Protection Systems

	Very Poor	Poor	Good	Very Good
R&D				
Time		X		
Human Resources / Cost			X	
Likelihood of Success		X		
DRDB R&D Capability			X	
Cdn External R&D Capability				X
Implementation				
Capital Cost			X	
O&M Cost			X	
Overall Rating				
Risk		X		
Benefit			X	

Research and Development Potential: There has been much research around the world to invent protective footwear that is effective against more than 25 grams of explosive. To date, this effort has met with limited success for larger charges, but the solutions are often unacceptable from an ergonomics point of view. This lack of success may be attributable to an incomplete comprehension of the mechanisms required to defeat the transmission of mine blast to the human leg.

Canadian Experience: DRDB and Canadian Industry have gained considerable knowledge about this problem over the past few years through a DIR project to explore novel foot protection concepts. These efforts have met with some success.

Relevance to Humanitarian Demining: The development of effective footwear is of considerable interest to the humanitarian demining community. There is also interest in finding out how effective current footwear, or the so-called blast boots, are.

Recommendation: Canadian industry is already involved in this type of development. CCMAT should endeavour to provide expert advice and T&E services wherever appropriate. Novel footwear concepts could be investigated at a later date based on the experience gained from early on activities.

Injury Mechanisms and Assessment Criteria

	Very Poor	Poor	Good	Very Good
R&D				
Time			X	
Human Resources / Cost		X		
Likelihood of Success				X
DRDB R&D Capability			X	
Cdn External R&D Capability			X	
--				
Implementation				
Capital Cost		X		
O&M Cost		X		
Overall Rating				
Risk			X	
Benefit				X

Research and Development Potential: There is a lot of on going research about this subject that involves many countries, Various projects bring together expertise from the branches of physics and medicine. The research is aimed at identifying the injury mechanisms at work with sufficient accuracy that meaningful countermeasures can be designed.

Canadian Experience: DRDB is currently involved in the above research with support from the Canadian Forces Medical Group. There is also much interest from Canadian Industry in this research.

Relevance to Humanitarian Demining: This research topic is key to several aspects of personnel protection and could have a large impact on the design of protective measures in humanitarian demining.

Recommendation: CCMAT should supplement existing military funding on this subject. The basic premise is that soldiers and deminers alike are human subjects and therefore, will equally benefit from this research. The principle avenue for cooperation is through funding of a test series with Frangible Surrogate Legs developed in Australia.

ENABLING TECHNOLOGIES

Geographic Information Systems

	Very Poor	Poor	Good	Very Good
R&D				
Time				X
Human Resources / Cost				X
Likelihood of Success			X	
DRDB R&D Capability				X
Cdn External R&D Capability				
Implementation				
Capital Cost				X
O&M Cost			X	
Overall Rating				
Risk				X
Benefit				X

Research and Development Potential: The technology is well developed from a research perspective, requiring only targeted development to meet the specific needs of the demining community.

Canadian Experience: GIS systems are in common use throughout Canada and numerous commercial firms and consultants have the expertise to integrate functional overlays specific to an application or user.

Relevance to Humanitarian Demining: This technology provides a basis for the management of mine action, including assessment of priorities. If data is sharable the assessment of priorities can be global in scope. The priority is to achieve standardization between mine action centres to allow cost reduction and data sharing.

Recommendation: The United Nations has directed one of its agencies to coordinate development of the needed functionality using a commercially available GIS software core. CCMAT will limit work in this area to contributing to the requirements defined for GIS functions and providing feedback on potential improvements.

Data Fusion

	Very Poor	Poor	Good	Very Good
R&D				
Time			X	
Human Resources / Cost			X	
Likelihood of Success			X	
DRDB R&D Capability			X	
Cdn External R&D Capability				
-				
Implementation				
Capital Cost		X		
O&M Cost			X	
Overall Rating				
Risk			X	
Benefit				X

Research and Development Potential: The technology is poorly delimited. Many disparate techniques would be considered data fusion depending on the context applied. No general technique has applicability to the broad range of detection phenomena and techniques that are of interest to mine detection. Specific techniques must be developed or assessed for each combination of detectors considered.

Canadian Experience: There is significant expertise in data fusion within Canada, both within DRDB and universities.

Relevance to Humanitarian Demining: Application of data fusion, in conjunction with multiple detectors, has the potential to slightly increase the detection probability and to significantly reduce the false alarm rate. Both results could increase productivity in mine action.

Recommendation: While data fusion has great potential impact in conjunction with the deployment of multiple sensor detector systems, no general data fusion technique has been identified that would be applicable to differing combinations of detector systems. The greatest promise appears to be in consolidating data fusion investigations into the overall detection analysis methods developed for specific combinations of detectors. Hence, CCMAT will not fund any work on data fusion outside the context of a specific detector or detector suite.

Mechanization And Automation

	Very Poor	Poor	Good	Very Good
R&D				
Time			X	
Human Resources / Cost			X	
Likelihood of Success				X
DRDB R&D Capability				X
Cdn External R&D Capability			X	
Implementation				
Capital Cost			X	
O&M Cost			X	
Overall Rating				
Risk				X
Benefit				X

Research and Development Potential: The mechanization requirements leverage well understood principles of engineering. Introduction of mechanization into mine action will require identification of mine action functions that can be most beneficially mechanized and proving technical and cost effectiveness. Limited automation functions are well understood, but existing implementations would be burdensome to field, require extensive training and technical support personnel.

Canadian Experience: Numerous Canadian companies and organizations have the mechanical design expertise to develop mine action equipment once the requirements have been specified. Fewer would have the insight into the neutralization and protection issues involved in developing appropriate specifications. DRDB and has extensive experience in the development and fielding of tele-operation systems that provide the level of automation required. A limited number of Canadian companies have direct expertise in the area.

Relevance to Humanitarian Demining: Mechanization has the potential to dramatically increase the productivity of mine action if concerns with respect to the clearance quality, system cost and operator safety can be addressed. Simple, effective tele-operation guarantees operator safety and may provide production efficiencies in and of itself.

Recommendation: Mechanization development will be limited to assisting prospective designers with technical guidance and test and evaluation capabilities in neutralization mechanisms and protection requirements. CCMAT will fund the development of low complexity tele-operation systems based on existing DND technology. This will be demonstrated with vehicle mounted vegetation clearance and mine detector systems to investigate and prove out the potential productivity gains in the direct context of mine action.

Position Measurement

	Very Poor	Poor	Good	Very Good
R&D				
Time			X	
Human Resources / Cost			X	
Likelihood of Success			X	
DRDB R&D Capability				X
Cdn External R&D Capability				X
Implementation				
Capital Cost			X	
O&M Cost			X	
Overall Rating				
Risk		X		
Benefit				X

Research and Development Potential: Accurate position and orientation measurement for ground vehicles is a proven technology, however, it relies on methods and instruments that are prohibitively expensive for routine use. Recent advancements in micro-machined sensors (MEMS technology) and analysis methods that heavily exploit differential GPS data within the constrained operational environment associated with mine action provide the potential to dramatically reduce the cost.

Canadian Experience: Numerous Canadian companies, consultants and organizations (including DRDB) have expertise related to navigation system development or in the development of related components. A few have experience in integrated navigation systems.

Relevance to Humanitarian Demining: Accurate position measurement is essential to the application of data fusion to multiple detector systems in order to allow the data from the same point on the ground to be identified for each detector as the vehicle moves. Accurate and repeatable position measurement would allow independent operation of multiple detector systems and/or neutralization systems operating on different vehicles. This would greatly increase the options available to the designer of a mine action "system".

Recommendation: CCMAT will fund the investigation of algorithms for high accuracy navigation systems based on lower cost components. If the algorithms prove successful, partially ruggedized prototypes will be implemented to fully trial and demonstrate the system under operational conditions.

CHAPTER TEN

PROGRAM RECOMMENDATICNS AND CONCLUSIONS

DEVELOPMENT OF A PROGRAM

Many factors had to be considered when developing the CCMAT R&D program. The scoping study exercise looked at a number of technological fields, many individual technologies, and applied an assessment process to ensure that only the most effective and practical technologies for humanitarian demining were selected. Considerable emphasis was placed on what the demining community has expressed as a priority. In particular, high cost solutions and difficult to sustain technologies were avoided. In rare instances some high tech solutions were considered if they were of particularly high value to the demining community. An example would be a relatively high tech solution which would be required for a short time and could be operated by contractor but would offer significant economies in a selected demining situation.

It is also recognized that demining technologies are experiencing considerable growth and innovative developments are being made throughout the world. The program should be flexible enough to adopt some of the new innovations where warranted, and conversely, it should drop those technologies which cannot or will not have a practical demining application. The CCMAT mandate will continue to be funded for approximately four years. This in turn has meant that only those technologies in a relatively advanced stage of development, and capable of completion in four years, should be considered.

The funding available to CCMAT is not sufficient to pursue all of the potential technologies. Approximately 17 million dollars was allocated to CCMAT. When one deducts $1.5 million allocated to landmine alternatives, $1.6 million CCMAT personnel costs, and the notional budget allocation of $3.9 million to Industry Canada for commercialization and marketing of Canadian products, the money remaining for the R&D program is approximately $10 million. In order to provide individuals responsible for each technological area an idea of the level of effort and funding that would be allocated to them, a series of meetings were held to apportion the funds for each field. The relative funding for each field are expressed as a percentage and actual money value in Table 2. This is assuming that $10 million is available for the R&D program. You will also note that a 10% contingency has been allocated. This permits program flexibility to augment areas with a funding shortfall, reinforce R&D successes, or to pursue short term R&D which becomes known in the future. A brief explanation of the rationale which led to the percentage allocations are provided in the paragraphs below.

TABLE 2

ALLOCATION OF FUNDS

Technology Field	% of Funds	Estimated Funds ($K)
Detection	32%	3200
Test & Evaluation	18%	1800
Protection	12%	1200
Neutralization	5%	500
Medical/Victim Assistance	8%	800
Enabling Technologies	12%	1200
Information & Dissemination	3%	300
Contingency	10%	1000
TOTALS	100%	10000

Once each technological area was assigned their "slice of the pie", they were able to prioritize their part of the R&D program and put forward a more detailed plan with objectives, how they were going to accomplish their objectives, and cost for each program element. Where possible, the R&D program was integrated with proposals from Canadian industry which had been forwarded to CCMAT for consideration. A summary of R&D objectives for each technological field is given at Table 3. High and low priorities are indicated and some technologies have been discarded. The discarded technologies have not been forgotten. Progress in these technologies will be monitored for significant advances, particularly R&D work done by other countries. However, it was felt that little could be achieved beyond what others were doing if CCMAT were to sponsor such technologies.

TABLE 3

R&D OBJECTIVES

TECHNOLOGY FIELD (a)	HIGH PRIORITY (b)	LOWER PRIORITY (c)	DISCARDED (d)
1. DETECTION	- T&E OF Smart Probe™ and follow-on development. - Point confirmation detector. - Characterize soil and effect on performance of metal detectors. - Discrimination capability for handheld detectors.	- Bioluminescence. - Long stand-off/ remote sensing of mined areas.	- Acoustic/seismic detectors. - High power microwave. - Enhanced infrared.
2. NEUTRALIZATION	- T&E support to industry. - Modification/ minor development of small scale systems.	- Point neutralization of mines with explosives or small scale equipment.	- Large scale mechanical neutralization systems e.g., soil mills, flails. - Large area

TECHNOLOGY FIELD (a)	HIGH PRIORITY (b)	LOWER PRIORITY (c)	DISCARDED (d)
			explosive neutralization devices.
3. PROTECTION	- Lower body protection. - Foot protection. - Head/eye protection. - Establish protection standards. - T&E support to industry.	- Upper body protection. - Hand protection. - Detailed injury mechanism studies.	- All round body protection. - Vehicle protection.
4. MEDICAL/VICTIM ASSISTANCE	- Assessment and minor upgrades to Trauma Kits. - Investigate practical, cost-effective solution to manufacture and fitting of artificial limbs.	- Feedback to medical staff.	- Development of new medical procedures or medical supplies.
5. ENABLING TECHS	- Produce simple generic tele-operation robotic kit for a wide variety of applications.	- Provide semi-autonomous capability to small scale equipment. - Automate highly repetitive tasks such as sweeping hand-held detectors.	- Geographical Information Systems. - Differential Global Positioning Systems. - Highly complex systems such as fully autonomous systems.
6. TEST & EVALUATION (T&E)	- Establish and operate T&E facilities for detection, protection and neutralization technologies. - Provide in-theatre trial support as requested by demining agencies.	- Participate in the establishment of international T&E Program (ITEP). - Conduct ITEP trials.	- T&E of large scale neutralization vehicles. - T&E of large scale explosive neutralization devices.

DETECTION

Detection was assigned the highest percentage of funding (32%). Detection is the key to effective mine clearance and is a fundamental requirement in all mine-affected countries. If a technical breakthrough in detection were possible, it would have a tremendous impact on demining safety and productivity. Most detection technologies are expensive to develop and some are in the medium to high technical risk category. In addition, there is a reasonable base of Canadian companies which can do competent work in

this field. The prospect of high payoff to the demining community for even an incremental improvement in detection capability warranted a relatively large budget for this technical field.

NEUTRALIZATION

Neutralization has been allotted a relatively small portion of the budget. This is for two reasons. Canadian industry already had products or ideas which did not require CCMAT support for development. Canadian industry has already responded with a number of proposals for mechanically based clearance systems and a novel point neutralization explosive device. Most of these proposals were either a private venture, required minimal development, or had already been developed for another application. The one important service that CCMAT could provide was T&E facilities and feedback from the testing whereby industry could improve their product. A large proportion of the budget is already allotted to this technological field where it will substantially benefit development of neutralization equipment and techniques. (See T&E below.)

PROTECTION

The CCMAT priority for protection is the provision of personal protective equipment against the effects of anti personnel mines. Numerous countries manufacture mine resistant vehicles and a Canadian contribution in this area would be too costly to pursue. Sufficient knowledge is available from military countermine R&D to manage any specific requirements should they arise. Personal protective equipment designed for deminers working in mined areas is an area where significant contributions could be made by Canadian industry and CCMAT. What is required by deminers in the field is a balance between comfort, functionality, and protection which permits effective use regardless of the environmental conditions. Companies making such equipment will require a T&E facility which can provide tests up to and including live mine trials. They will also require advice on the nature of the landmine threat, determining equipment shortfalls and advice/assistance in how to overcome those shortfalls. Particular emphasis will be given to protection of the lower limbs, face and neck.

Another major contribution that CCMAT can make to the demining community is determination and establishment of satisfactory protective criteria for protection against the anti personnel mine threat. This will be derived from fundamental studies which have already started into the precise injury mechanism of mines against the human body. From these studies it should be possible to provide improved protection standards and possibly model the mine effects to the extent that computer models may be used to reduce R&D effort in protective equipment design.

TEST AND EVALUATION

Regardless of what is developed in-house or by Canadian industry, there is a need for scientifically sound and credible test and evaluation facilities. Numerous shortfalls in T&E capability were known to exist, and facilities had to be established or upgraded to meet humanitarian demining requirements. Upgrading and construction to overcome the shortfalls, as identified in Chapter 8 started in late 1998 and is scheduled for completion in 1999. This rapid start up was considered essential if meaningful equipment tests were to be conducted early in the CCMAT mandate. As of early

1999 T&E, had already been conducted on Smart Probe™ at Suffield and in Cambodia, and preliminary trials had been made on personal protective equipment. Approximately $1.5 million will be required for T&E facilities and associated equipment. In addition to providing industry with accurate feedback on equipment performance, the humanitarian demining community will have high quality test results upon which to base procurement decisions. Two other aspects of T&E will be served by the improvements to the test facilities. Canada can then participate as a full-fledged member within the International T&E Program (ITEP) and thereby gain access to all other ITEP T&E results and at the same time provide a valued service to the demining community at large. In addition, CCMAT will have a capability to provide in-theatre T&E service to mine action agencies in mine affected countries. The experience that DRES has had in such testing has been most appreciated in the past by mine action agencies by providing timely, detailed advice on equipment performance in the environment in which the demining equipment will be used.

GLOSSARY

Anti-Personnel Mine - An explosive or material, normally encased, designed to wound, kill or otherwise incapacitate personnel. It may be detonated by the action of its victim, by the passage of time or by controlled means.

Anti-Tank Mine - A mine which is designed to disable or destroy vehicles and tanks. The explosive can be activated by many types of fuse mechanism normally by pressure, tilt rod, influence or command detonated.

Booby Trap - Any device or material which is designed, constructed or adapted to kill or injure and which functions unexpectedly when a person or object (vehicle) disturbs or approaches an apparently harmless object or performs an apparently safe act.

Breaching - Operations which clear a path through a mine field using a variety of military equipment, manual means, Mine Detecting Dogs or mechanical means.

Clearance - Clearing an area of all mines, UXO and IED to a predefined standard.

Clearance Standards - The standards that are to be applied to clearance operations. Normally specified in the contract document or clearance plan. In the UN it is normally achieved to a clearance standard of 100 per cent with a tolerance error of not more than 0.4 per cent.

Demining - Term used to describe all aspects of mine clearance (see mine clearance).

Explosive Ordnance - Munitions that contain explosives, nuclear fission or fusion material, biological and chemical agents. This includes bombs and warheads, guided and ballistic missiles, artillery, mortar, small arms ammunition, mines, torpedoes, depth charges, demolition stores, pyrotechnics, cluster munitions and dispensers, cartridges and propelled actuated devices, electric explosive devices and similar items that are explosive in nature.

Explosive Ordnance Disposal (EOD) - The detection, identification, field evaluation, render safe, recovery and disposal of Unexploded Ordnance (UXO). EOD may be undertaken:

a. as a routine part of mine clearance operations, upon the discovery of UXO;

b. to dispose of UXO discovered outside mined areas (this may be a single UXO, or a larger number inside a specific area);

c. to dispose of explosive ordnance which has become hazardous by damage or destruction.

Hand Clearance - The act of clearing hazardous areas manually. Normally refers to clearance teams using mine detectors and probes.

Humanitarian Mine Clearance - The removal of mines and UXO under the auspices of a humanitarian organization in order to allow the land to be returned to the local community.

Mine - An explosive or other material, normally encased, designed to destroy or damage vehicles, boats, or aircraft, or designed to wound, kill, or otherwise incapacitate personnel. It may be detonated by the action of its target, the passage of time or by controlled means (NATO definition).

Mine Action - All aspects of a national programme to address the mine problem in a country.

Mine Action Centre - Mine Action Centre usually refers to a facility, containing personnel who coordinate and assist the national mine action activities in a country.

Mine Awareness - A method of informing, teaching and relaying messages about landmines to the public, normally through a programme of education. Mine awareness encompasses mine risk education, mine awareness training (MAT) for peacekeepers, multi-media presentations, and what action to take when a mine or UXO is found. It is intended to modify behaviour patterns to reduce casualties. A result of Mine Awareness is the flow of information back to a MAC about mine and ordnance locations.

Mine Clearance - The clearance of mines and UXO from a specified area to a predefined standard.

Minefield Survey - One of three disciplines in demining which involves the gathering of intelligence in order to identify suspect or known minefields areas. It also involves the reduction and marking of the areas prior to demining activities. There are three levels of survey (see Survey).

Minimum Metal Content - A term given to both AT and AP mines, but more commonly to AP mines with a limited amount of metal content. Minimum metal content mines normally have a few very small components of metal, for example a spring, ball bearing/s and the striker pin. In addition these metal components may have been manufactured from specialised material such as certain stainless steels which can be difficult to detect. It has been recommended that protocol II of the Geneva Convention be amended to specify that a newly manufactured mine must have a metal content of at least 8 grams.

Neutralization - The process whereby a mine is destroyed, removed for disposal, or otherwise rendered safe and does not pose a threat to general population.

Non-Metallic Mine - A mine that contains no metal content but is a title often used, incorrectly, for mines that have minimum metal content.

Probe - A tool, consisting of one or more pointed rods or tines that is used to probe the subsurface of the ground at a predetermined angle in order to locate buried ordnance. Also known as a prodder.

Survey - The method of determining the land location of suspect or verified mined areas and further determining through survey methods the perimeters of the actual mined area. This is undertaken by use of three levels of survey:

- Level one: General Survey
- Level two: Technical Survey
- Level three: Completion Survey

UNCLASSIFIED
SECURITY CLASSIFICATION OF FORM
(highest classification of Title, Abstract, Keywords)

DOCUMENT CONTROL DATA

(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)

1. ORIGINATOR (the name and address of the organization preparing the document. Organizations for who the document was prepared, e.g. Establishment sponsoring a contractor's report, or tasking agency, are entered in Section 8.)
Canadian Centre for Mine Action Technologies
Defence Research Establishment Suffield
Box 4000, Stn Main, Medicine Hat AB T1A 8K6

2. SECURITY CLASSIFICATION
(overall security classification of the document, including special warning terms if applicable)
Unclassified

3. TITLE (the complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S, C or U) in parentheses after the title).

Scoping Study for Humanitarian Demining Technologies (U)

4. AUTHORS (Last name, first name, middle initial. If military, show rank, e.g. Doe, Maj. John E.)

Edited by Carruthers, Major Al

5. DATE OF PUBLICATION (month and year of publication of document)

September 1999

6a. NO. OF PAGES (total containing information, include Annexes, Appendices, etc)

125

6b. NO. OF REFS (total cited in document)

72

7. DESCRIPTIVE NOTES (the category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)

Technical Report

8. SPONSORING ACTIVITY (the name of the department project office or laboratory sponsoring the research and development. Include the address.)

Canadian Centre for Mine Action Technologies

9a. PROJECT OR GRANT NO. (If appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant.)

9b. CONTRACT NO. (If appropriate, the applicable number under which the document was written.)

10a. ORIGINATOR'S DOCUMENT NUMBER (the official document number by which the document is identified by the originating activity. This number must be unique to this document.)

DRES TR 1999-121

10b. OTHER DOCUMENT NOs. (Any other numbers which may be assigned this document either by the originator or by the sponsor.)

11. DOCUMENT AVAILABILITY (any limitations on further dissemination of the document, other than those imposed by security classification)

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ABSTRACT

This report presents the results of a study carried out for the Canadian Centre for Mine Action Technologies (CCMAT). The aim of the study was to recommend a research and development program in humanitarian land mine detection for the 5 year mandate of the Centre.

Current demining practices and problems, grouped according to survey level, are presented from a technical viewpoint. Demining needs are then presented in the same fashion. Next, brief reviews of the Canadian and worldwide landmine detection research and development programs are presented to establish the current research and development status.

An assessment of technologies is then presented to determine future research and development directions for CCMAT. The general methodology used in a previous Defence Research and Development Branch countermine long term technology assessment was employed, but the guidelines were modified to reflect the differences between the requirements of humanitarian demining and those of countermine. Prescreening eliminated numerous technology areas and assessments were presented only for twelve general technology areas which have some potential and/or novelty.

Based on the above assessment and requirements, a two component program in landmine detection is proposed. The first component is an evaluation program for existing and future commercial off-the-shelf and prototype detectors. The second component is an in-house and contracted research and development program to develop detectors and assisting technology specifically for humanitarian demining.

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KEYWORDS:
- Humanitarian Demining
- Technology Description and Assessment

DESCRIPTORS:
- Landmine Detection
- Mine Neutralisation
- Personal Protection
- Landmine Clearance
- R&D Program
- Landmine Clearance
- Canadian Centre for Mine Action Technologies (CCMAT)

#512128